# Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL

D R A F T

California Regional Water Quality Control Board
Los Angeles Region

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## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# 1 INTRODUCTION



Machado Lake, located in the Dominguez Channel watershed in southern Los Angeles County, is identified on the 1998 and 2002 Clean Water Act 303(d) list of impaired water bodies as impaired due to eutrophic conditions, algae, ammonia, and odors. Approved 303(d) listings require the development of a total maximum daily load (TMDL) to establish the amount of pollutants a waterbody can receive without exceeding water quality standards. As documented in this staff report, the Machado Lake eutrophic, algae, and odor impairments are caused by excessive loading of nutrients, including nitrogen and phosphorus, to Machado Lake. Ammonia was found to be at levels below the toxicity standards, but that contribute to the total nitrogen loading. The Machado Lake TMDL presents the elements necessary for addressing eutrophic, algae, ammonia and odor impairments to Machado Lake. In accordance with a consent decree, this TMDL addresses the waterbody with eutrophic, algae, ammonia, and odor listings in analytical unit 76.

## 1.1 REGULATORY BACKGROUND

Section 303(d) of the Clean Water Act (CWA) requires that “Each State shall identify those waters within its boundaries for which the effluent limitations are not stringent enough to implement any water quality standard applicable to such waters.” The CWA also requires states to establish a priority ranking for waters on the 303(d) list of impaired waters and establish TMDLs for such waters.

The elements of a TMDL are described in 40 CFR 130.2 and 130.7 and Section 303(d) of the CWA, as well as in the U.S. Environmental Protection Agency guidance (U.S. EPA, 2000). A TMDL defined as the “sum of the individual waste load allocations for point sources and load allocations for nonpoint sources and natural background” (40 CFR 130.2) such that the capacity of the waterbody to assimilate pollutant loadings (the Loading Capacity) is not exceeded. TMDLs are also required to account for seasonal variations, and include a margin of safety to address uncertainty in the analysis.

States must develop water quality management plans to implement the TMDL (40 CFR 130.6). The U.S. EPA has oversight authority for the 303(d) program and is required to review and either approve or disapprove the TMDLs submitted by states. If the U.S. EPA disapproves a TMDL submitted by a state, U.S. EPA is required to establish a TMDL for that waterbody. A schedule for development of TMDLs in the Los Angeles Region was established in a consent decree (Heal the Bay Inc., et al. v. Browner C 98-4825 SBA) approved on March 22, 1999. The consent decree combined waterbody pollutant combinations in the Los Angeles Region into 92 TMDL analytical units. In accordance with the consent decree, this document summarizes the analyses performed and presents the TMDL for nitrogen and phosphorus compounds and related effects for Machado Lake (analytical unit 76).



## 1.2 ELEMENTS OF A TMDL

There are seven elements of a TMDL. Sections 2 through 7 of this document are organized such that each section describes one of the elements, with the analysis and findings of this TMDL for that element. The elements are:

- Section 2: Problem Identification. This section reviews the data used to add the waterbody to the 303(d) list, and summarizes existing conditions using that evidence along with any new information acquired since the listing. This element identifies those beneficial uses that are not supported by the waterbody; the water quality objectives (WQOs) designed to protect those beneficial uses; and summarizes the evidence supporting the decision to list each reach, such as the number and severity of exceedances observed.
- Section 3: Numeric Targets. The numeric targets for this TMDL are based upon the WQOs described in the Basin Plan
- Section 4: Source Assessment. This section develops the quantitative estimate of loading from point sources and non-point sources into Machado Lake
- Section 5: Linkage Analysis. This analysis shows how the sources of pollutants into the waterbody are linked to the observed conditions in the impaired waterbody.
- Section 6: Pollutant Allocation. Each pollutant source is allocated a quantitative load that it can discharge to meet the numeric targets. Allocations are designed such that the waterbody will not exceed numeric targets for any of the compounds or related effects. Allocations are based on critical conditions, so that the allocated pollutant loads may be expected to remove the impairments at all times.
- Section 7: Implementation. This section describes the plans, regulatory tools, or other mechanisms by which the waste load allocations are to be achieved. The TMDL

provides cost estimates to implement best management practices (BMPs) required throughout the Machado Lake watershed to meet water quality objectives in the lake.



## 1.3 Environmental Setting

Machado Lake is located in the Ken Malloy Harbor Regional Park (KMHRP), which is a 231 acre Los Angeles City Park serving the Wilmington and Harbor City areas. (Figure 1) The Park is located west of the Harbor freeway (110) and east of Vermont Street between the Tosco Refinery on the south and the Pacific Coast Highway on the North. Machado Lake is one of the last lake and wetland systems in Los Angeles; the area is approximately 103.5 acres in total size. The upper portion, which includes the open water area, is approximately 40 acres and the lower wetland portion is about 63.5 acres. This TMDL will address the 40 acre open water lake. The lake was originally developed as part of Harbor Regional Park in 1971 and intended for boating and fishing. Over the years water quality generally declined; boating was stopped and signs were posted warning of the risk of eating fish from the lake.

Machado Lake is located within the Machado Lake Sub-watershed which is approximately 20 square miles and positioned within the larger 110 square mile Dominguez Channel Watershed. The watershed is located in southern Los Angeles County and includes all or a portion of the following communities: Harbor City, Los Angeles, Torrance, Carson, Lomita, Rolling Hills, Rolling Hills Estates, and Palos Verdes Estates. (Figure 2) The dominant land use in the Machado Lake Watershed is high density single family residential accounting for approximately 45 % of the land use. Industrial, vacant, retail/commercial, multi-family residential, transportation, and educational institutions each account for 5-7 % of the land use while “all other” accounts for the remaining 23 %. Machado Lake is a receiving body of urban and stormwater runoff from a network of storm drains throughout the watershed. There are three discharge points into Machado Lake from the following storm drain channels: (Figure 3)

- Wilmington Drain
- Project No. 77
- Harbor City Relief Drain.

Approximately 88 % of the Machado Lake Watershed area flows through the Wilmington Drain into Machado Lake.

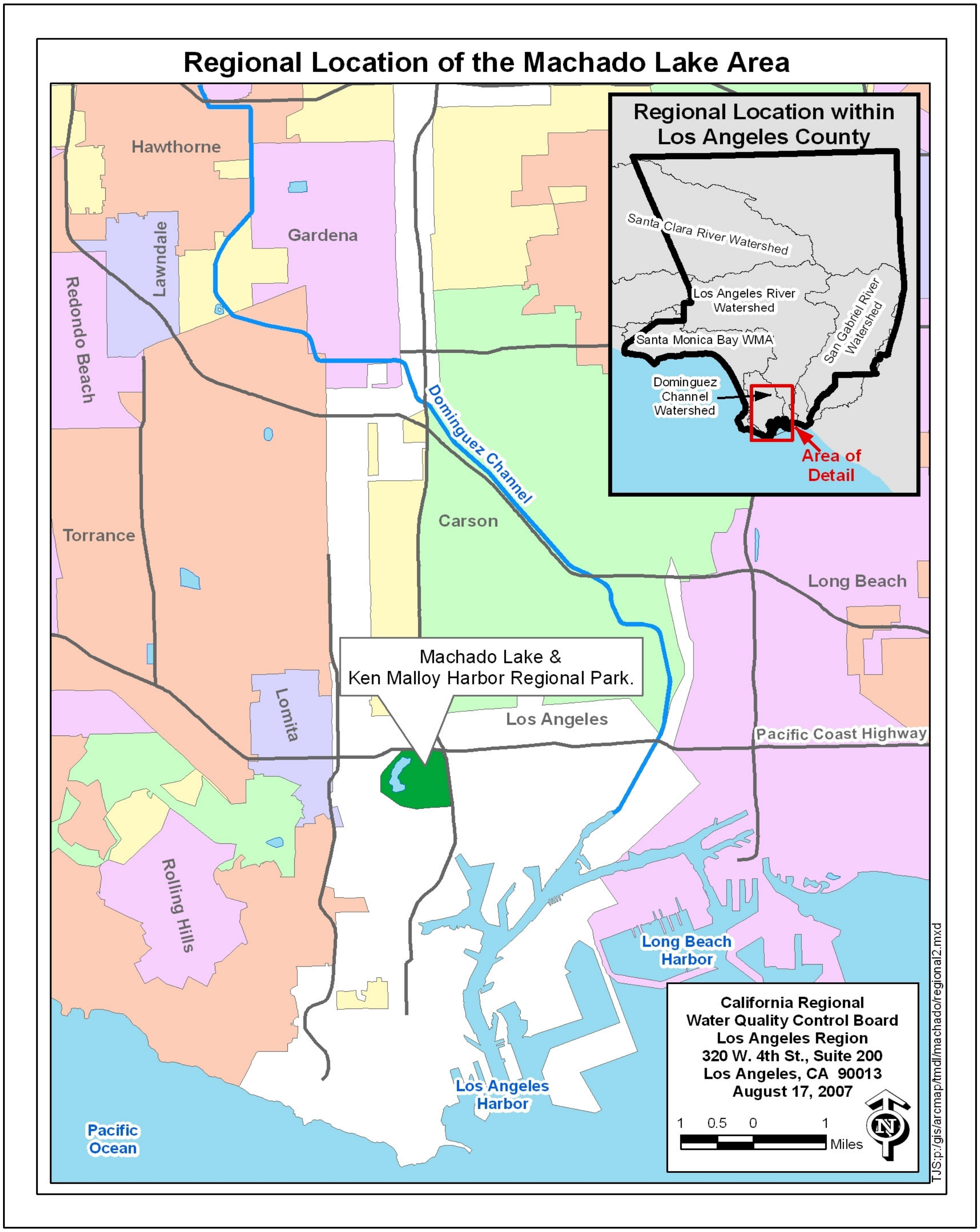


**Figure 1 Machado Lake regional location map**

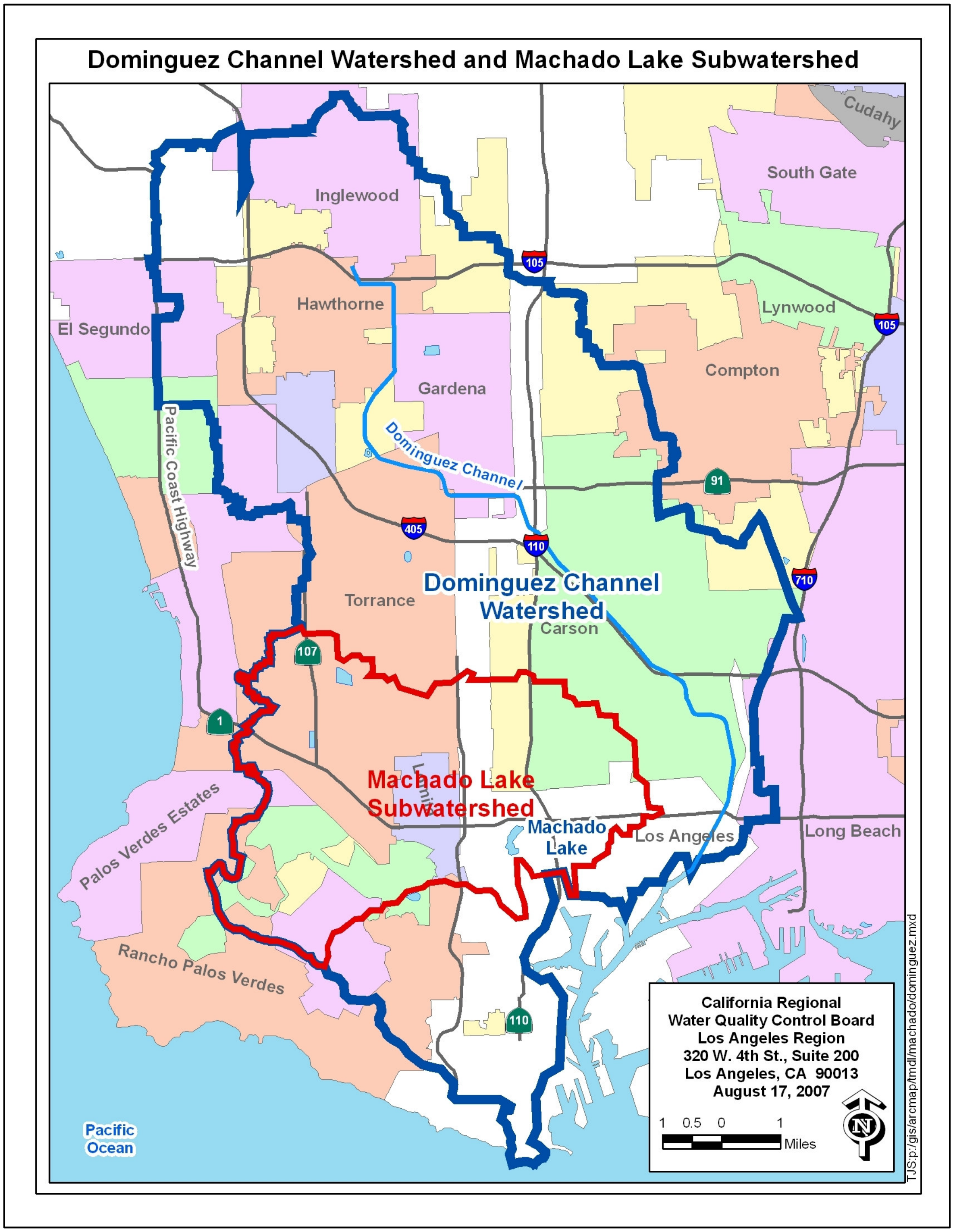


**Figure 2 Dominguez Channel watershed and Machado Lake subwatershed map**

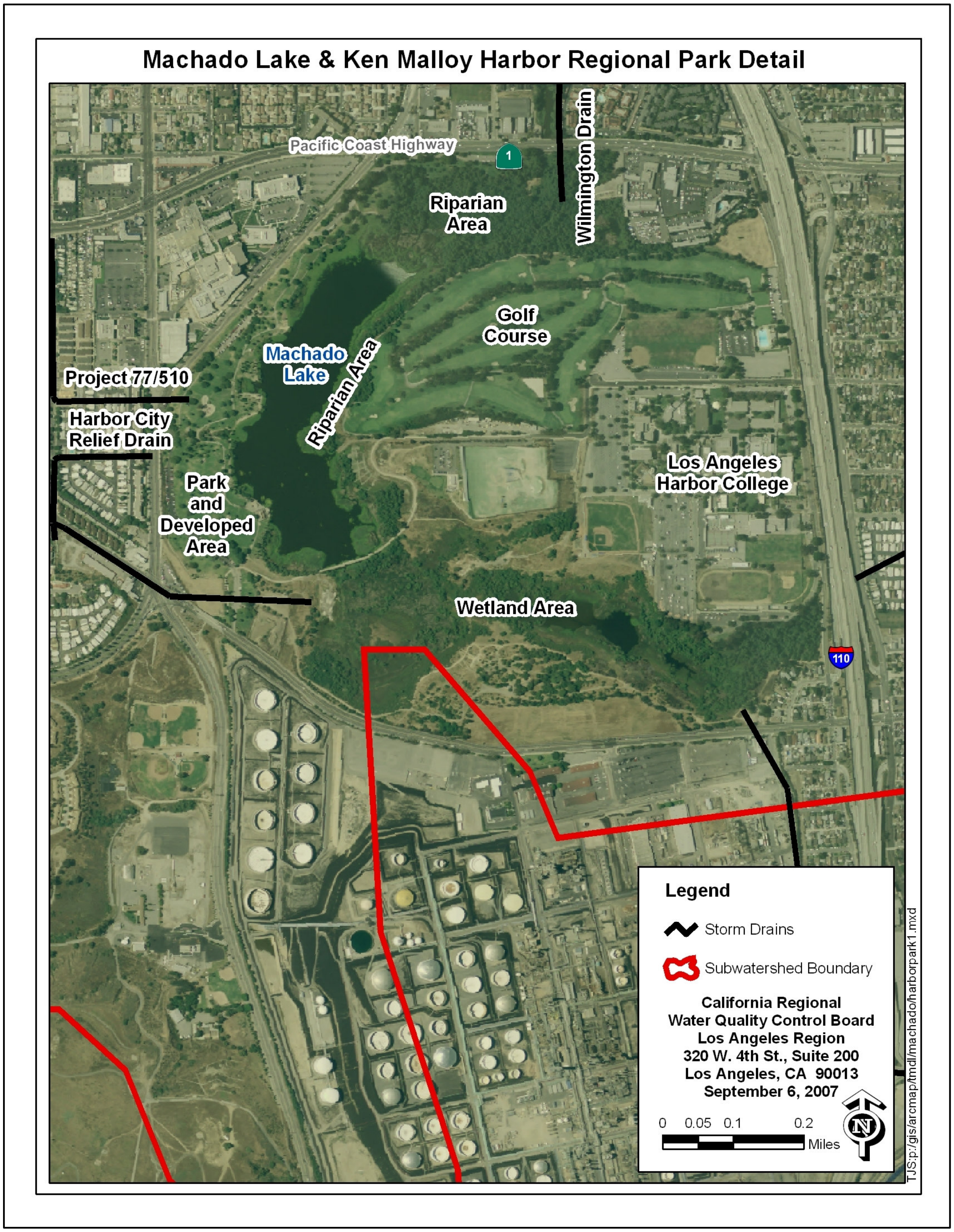


Figure 3 Machado Lake and Ken Malloy Harbor Regional Park Overview

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Machado Lake is part of one of the last freshwater wetland habitats in Los Angeles area. Although the lake is generally located in a highly urbanized area, it is surrounded by critical habitat and designated a significant ecological area by Los Angeles County (Basin Plan, p 1-17). Immediately bordering the lake are emergent wetland vegetation types such as bulrushes, cattails, and water primrose. On the north end of the lake, near the Wilmington Drain inlet, there is a well established willow riparian forest and an area where cottonwoods and sycamore have been planted. The willow riparian habitat continues along the east side of the lake creating a buffer between the lake and the Harbor Regional Golf Course. South of the lake, below the dam, is a 63 acre seasonal wetland; this area contains several sensitive habitats and vegetation types. The west side of the lake is landscaped and considered the active recreation area for activities such as picnicking. There have been several recent sightings of threatened and endangered bird species residing and foraging in the area; Regional Board staff has observed least terns foraging at the lake.

Machado Lake is a shallow polymictic lake; the depth is generally 0.5 – 1.5 meters; the average depth is approximately 1.0 meter. The northwest portion of the lake is slightly shallower (approximately 0.6- 0.9 meters deep). Machado Lake has been beset with water quality problems such as algal blooms and low dissolved oxygen concentrations during summer months. There is a well established macrophyte community along the edge of the lake. The water normally has a brown – yellowish tint throughout the year, but, the lake can be green and subject to algal blooms in the summer months. The fish population includes goldfish, carp, and largemouth bass.

# 2 PROBLEM IDENTIFICATION

## 2.1 NUTRIENT ENRICHMENT PROBLEMS

Eutrophication and nutrient enrichment problems rank as the most widespread water quality problems for lakes nationwide; more lake acres are affected by nutrients than any other pollutant or stressor (EPA 2000). Eutrophication is defined by increased nutrient loading to a waterbody and the resulting increased growth of biota, phytoplankton and other aquatic plants. Phosphorus and nitrogen are recognized as key nutrients for phytoplankton growth in lakes and are responsible for the eutrophication of surface waters. Schindler (1974) unquestionably demonstrated this with his work in the experimental lakes areas of Ontario Canada. In Lake 227, Schindler added phosphate and nitrate to the lake and within weeks the lake was transformed into a “teeming green soup”. In order to expand on the results from Lake 227, an additional experiment was conducted in Lake 226. Lake 226 was divided at a narrow section by a sea curtain and then nitrogen and carbon were equally added to both basins; phosphorus was added to only one basin (Schindler 1974). Within four months the basin that had received the phosphorus additions was covered with a bloom of blue green algae *Anabaena spiroides*, while the basin that had only received nitrogen and carbon had phytoplankton assemblages and densities that were similar to that at the start of the project. These classic studies have become the benchmark of what is expected from high nutrient loading in lakes, particularly when phosphorus is the limiting nutrient.



Furthermore, there have been cases in which lakes are degraded by eutrophic conditions as a result of excessive nutrient loading from sources such as sewage effluent. Both Lake Erie and Lake Washington are considered success stories for lake recovery after the diversion of nutrient-rich sewage effluent. In reaction to severe eutrophication in Lake Erie, the United States and Canada signed the Great Lakes Water Quality Agreement in 1972. In 1978 the agreement was renewed and included specific phosphorus targets and load reduction requirements (Great Lakes Water Quality Agreement of 1978, Annex 3), which helped to alleviate the eutrophic conditions of Lake Erie. Lake Washington was the receiving water for discharge from 10 wastewater treatment plants, which contributed about 56 percent of the phosphorus to the lake (Edmondson, 1970). As the nutrient load continued, the lake began to show degrading water quality, particularly with *Oscillatoria rubescens* (a blue green algae) becoming prominent in the phytoplankton community. Once the wastewater discharge was diverted, the lake quickly responded with a decrease in phytoplankton biomass, increased transparency, and a disappearance of *Oscillatoria rubescens* (Edmondson, 1994). As a result of designed whole lake experiments and nutrient loading/nutrient reduction studies, it is clear that phosphorus and nitrogen are intrinsically linked to the key symptom of eutrophication, excessive algal growth. Thus, nutrient standards and/or TMDL listings for eutrophic conditions generally focus on these two constituents.

In general, a pollutant loaded into a waterbody is often discharged to that waterbody from an external source (i.e. external loading); in the case of nutrients external sources are often publicly owned treatment works (POTW), septic systems, and urban runoff. However, in lakes it is also common for pollutants, particularly nutrients, to be recycled within the lake. The key processes for internal nutrient recycling (internal loading) is the exchange of phosphorus across the sediment water interface. The exchange of phosphorus between the sediments and the water is a major part of the phosphorus cycle in lakes. The rate at which phosphorus sinks into the sediments and the rate at which sediment processes function to regenerate the phosphorus back to the water column depends upon many physical, chemical and biological factors. Phosphorus transport to the sediments can occur by various processes such as (1) sedimentation of phosphorus minerals imported from the surrounding watershed, (2) sedimentation with organic matter, and (3) phosphorus adsorption or precipitation with inorganic compounds (Wetzel, 2001). Once the phosphorus is in the lake sediments, numerous processes (e.g. desorption and or microbiological activities) operate, often simultaneously, to mobilize phosphorus from particulate storage to phosphorus dissolved in the sediment water. Once in the dissolved state residing in the sediment interstitial water, phosphorus can be easily transported into the water column where it is available again for biological activities such as algae growth.

Figure 4 shows the conceptual transport of phosphorus from the various sediment layers to the water column. The mechanisms to transport the phosphorus from the sediment water to the overlying water column include diffusion, wind-induced turbulence, which can resuspend sediment particles, and sediment disturbance caused by bottom feeding fishes (Wetzel, 2001). These transport mechanisms also work to release nitrogen from the sediments into the water. During periods when external loading is reduced, such as the dry season, the internal recycling of nutrients is very important for phytoplankton growth and general lake water quality.

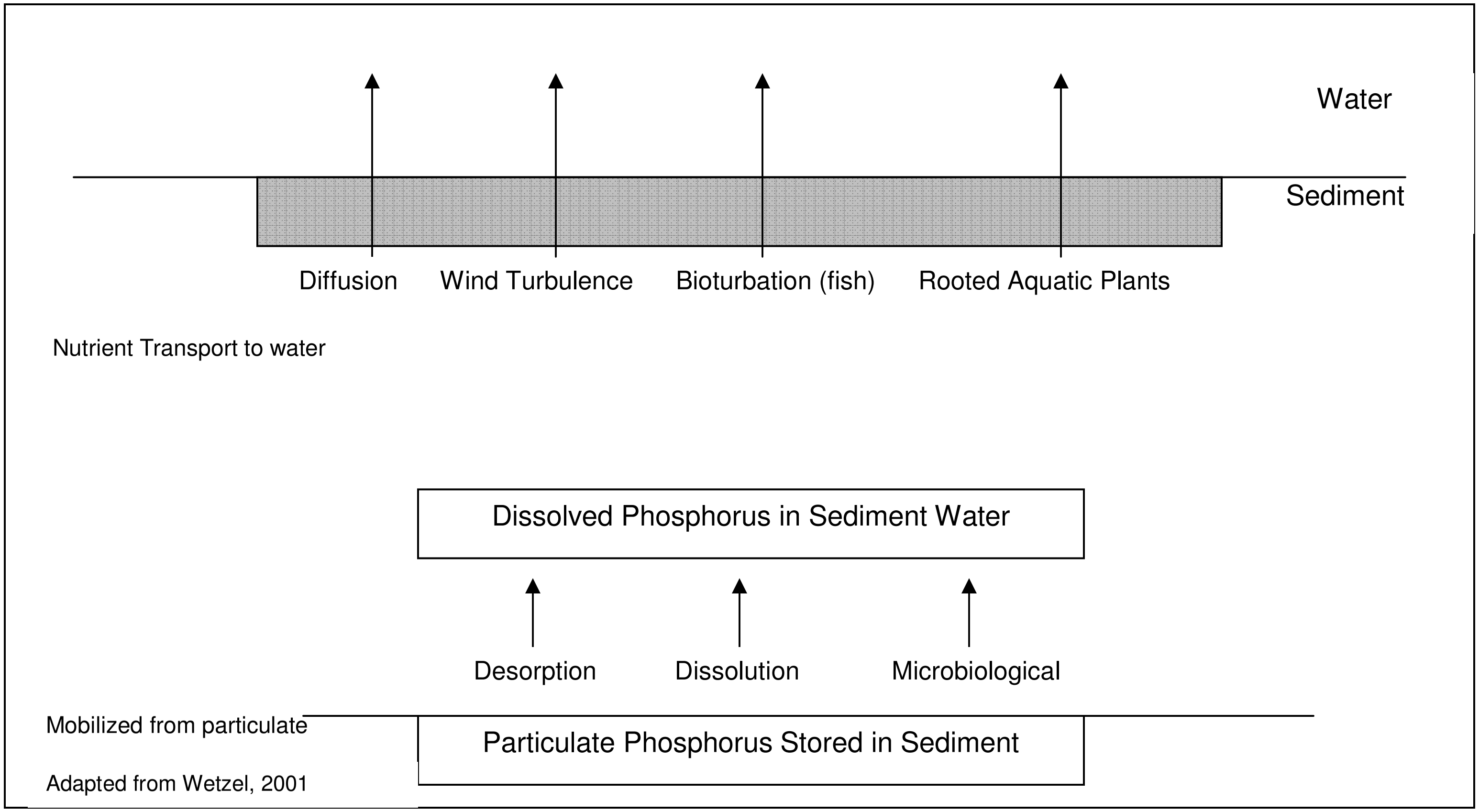



**Figure 4 Example processes to mobilize and transport phosphorus from sediments to water column**

Wind induced sediment resuspension is often an important type of internal loading in shallow lakes. Sediment resuspension has been satisfactorily predicted in a number of studies with relationships that use wind speed, wind direction, fetch and depth to sediment to estimate the degree of resuspension (Carper and Bachmann 1984). Bloesch 1995, showed that sediment resuspension and erosion of fine-textured bottom sediment occurred when deep-water waves entered water shallower than one-half the wavelength. It is the transition from deep water to shallow water which creates the situation for sediment resuspension. As the wind blows over the water it sets the water surface in motion. In the case that the depth of the water is greater than one half the wavelength, a deep water wave will be generated and move in a circular orbit (Wetzel, 2001). As the wave moves into shallow waters (water depth less than one half the wavelength), the orbit of the wave's motion will become deformed from circular to elliptical as a result of interaction with the bottom sediments (Wetzel, 2001). This interaction in the shallow regions of the lake disturbs the bottom sediments and creates sediment resuspension, which can provide nitrogen and phosphorus back into the water column for biological activities. The wavelength (L) of a deepwater wave is related to its period, T, by the relation:

$$L = gT^2/2\pi \qquad \textbf{Equation 1}$$

Where g is the gravitational constant (Martin and McCutcheon, 1999). A wave's period can be estimated using the empirical equation developed by the US Army Coastal Engineering Research Center (Carper and Bachmann, 1984) that states:

$$T = 2.4\pi U \tanh [0.077 (gF/U^2)^{0.25}] / g \qquad \textbf{Equation 2}$$

Where U is the wind speed and F is the fetch. These elements of sediment resuspension will be applied to Machado Lake as part of the TMDL source assessment.

### 2.1.1 Nutrient Concentration and Algal Biomass – Conceptual Model

As discussed, excessive algal growth is a result of excessive nutrient concentrations and is one of the primary symptoms of eutrophic conditions. Therefore, it is reasonable to estimate the concentration of algal biomass (chlorophyll *a*) based on the concentration of phosphorus and/or nitrogen in the lake. There are several studies which developed empirical relationships to predict chlorophyll *a* concentrations based on total nutrient concentrations.

Dillon and Rigler (1974) developed an empirical equation to predict summer chlorophyll concentrations (chl a) from the total phosphorus (TP) concentration in lakes at spring turnover. The regression line calculated as part of this study is a follows:

$$\text{Log Chl a} = -1.136 + 1.449 \log \text{TP}$$

The correlation coefficient for this relationship was calculated as 0.95.

Similarly, the equation developed by Jones and Bachmann (1976) was based primarily on literature values, although some were measured values, of summer total phosphorus and chlorophyll *a* from 159 lakes covering a broad range of trophic levels. A very strong relationship was found ($r = 0.95$) between the July – August average of chlorophyll *a* and total phosphorus.

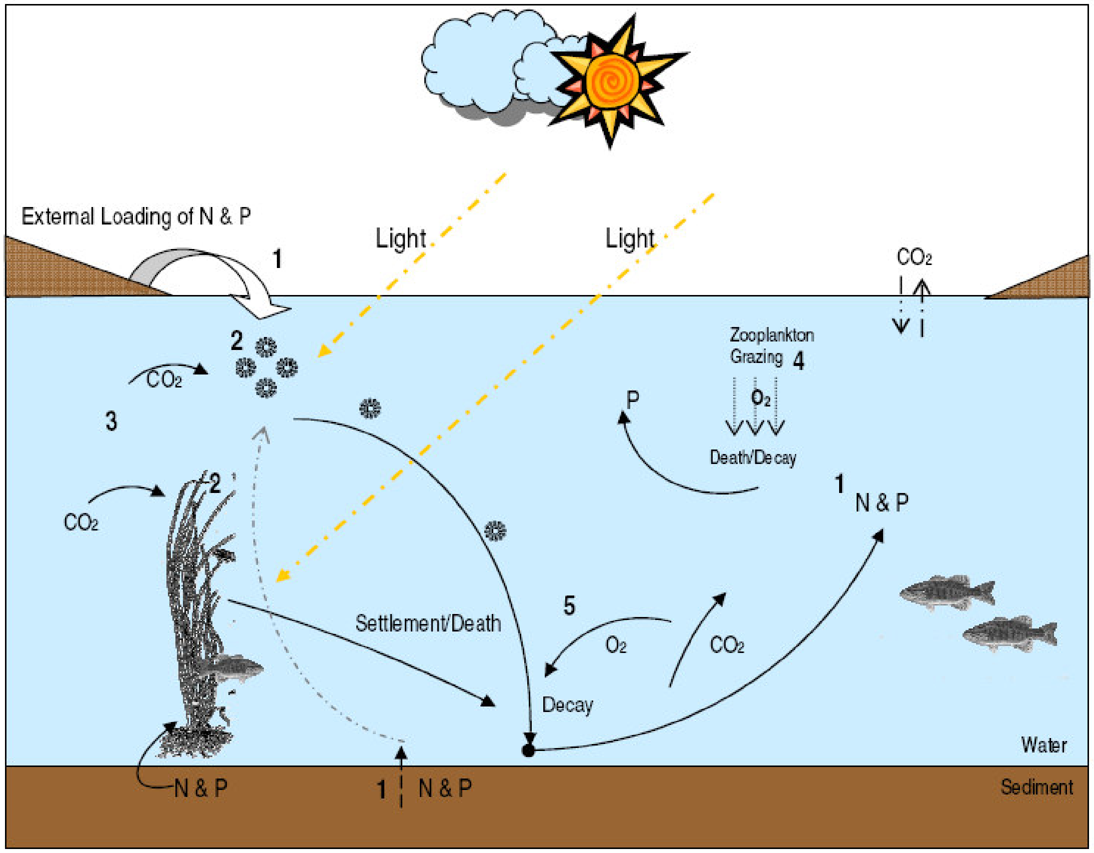
$$\text{Log Chl a} = -1.09 + 1.46 \log \text{TP}$$

When considering the different types of lakes included in this study including wide geographic distribution there is strong implication that phosphorus is the element controlling algal biomass in a broad range of lakes. As a result of these studies and others similar to them, the importance of phosphorus in determining lake algal biomass has been well established. However, not all lakes respond similarly to phosphorus (Canfield, 1983). The different response is due to the fact that other parameters can affect algal biomass such as, light or situations in which nitrogen may be the limiting nutrient. To explore how nitrogen may be playing a role in the growth of algal biomass, especially in situations where nitrogen is the limiting nutrient, Canfield (1983) developed an empirical relationship based on data from 223 Florida lakes ($r^2 = 0.81$).

$$\text{Log Chl a} = -2.49 + 0.269 \log (\text{TP}) + 1.06 \log (\text{TN})$$

Many of the lakes included in this study were nitrogen limited lakes and the relationship presented here demonstrated the strongest relationship between total nutrient concentrations and algal biomass. Likewise, this equation from Canfield's study has the best correlation between measured and predicted chlorophyll *a* values (r = 0.89). Thus, there are some lakes, generally nitrogen limiting lakes, in which total phosphorus and nitrogen should be considered together when estimating algal biomass.

There are many biological responses to nutrients (nitrogen and phosphorus) in lakes. The following conceptual model (Figure 5) outlines the basics of nutrient cycling in lakes. The biologically available nutrients and light will stimulate phytoplankton and or macrophyte growth. As these plants grow they provide food and habitat for other organisms such as zooplankton and fish. When the aquatic plants die they will release nutrients (ammonia and phosphorus) back into the water through decomposition. The decomposition of plant material consumes oxygen from the water column; in addition the recycled nutrients are available to stimulate additional plant growth. Physical properties such as light, temperature, residence time, and wind mixing also play integral roles throughout the pathways described.




1. Nutrients (N and P) enter the lake through external loading from the surrounding watershed and internal recycling processes
2. Nutrients and light stimulate the growth of phytoplankton and macrophytes (aquatic plants)
3. Aquatic plants consume carbon dioxide and the increase the pH of the lake
4. Zooplankton (aquatic invertebrates) graze the phytoplankton population
5. Aquatic plants break down and or die and consume oxygen as part of decomposition and recycle ammonia, phosphorus, and carbon dioxide into the water and the sediments

Adapted from EPA 1999

**Figure 5 Conceptual Model of Lake Processes**

These typical biological processes can become over stimulated by the addition of excess nutrients to the lake and create a situation in which water quality becomes degraded and beneficial uses are impaired. The following flow chart (Figure 6) outlines the responses within the lake to excessive nutrient loading and how the beneficial uses will be impacted.

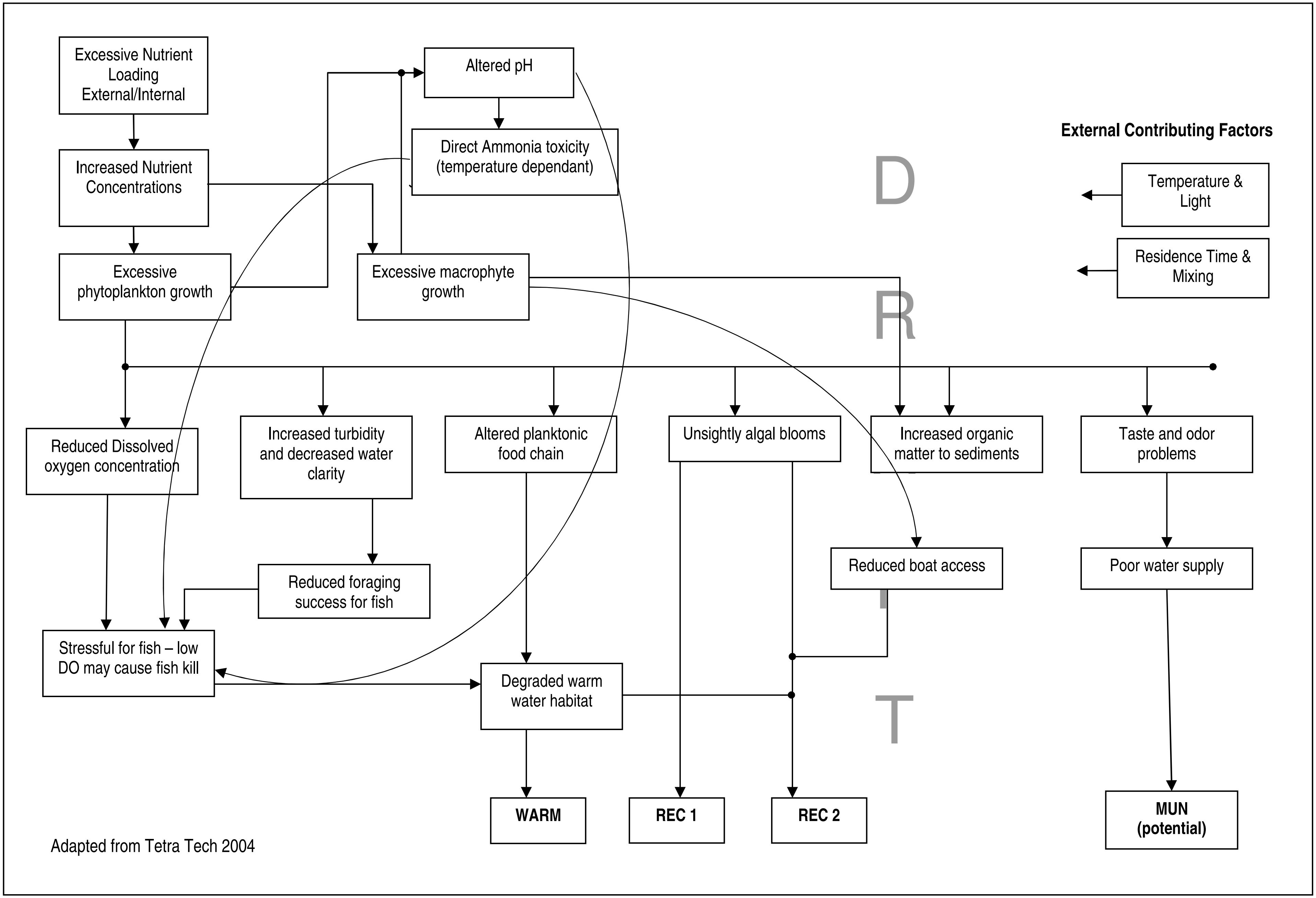



**Figure 6 Conceptual model for nutrient impaired lake leading to impaired beneficial uses**

Excessive nutrient loading, from either external or internal process, will lead to excessive phytoplankton and macrophyte growth, which are often considered the primary problems associated with increased nutrient concentrations in lakes. This excessive plant biomass may cause increased turbidity, altered planktonic food chains, algal blooms, reduced dissolved oxygen concentrations, and increased nutrient recycling (Figure 6). These changes can lead to a cascade of biological responses culminating in impaired beneficial uses.



Typically, excessive plant growth can quickly lead to an altered planktonic community; in many cases the dominant phytoplankton species may become blue green algae and algal blooms may occur, especially in the summer months. Likewise, macrophyte growth may increase and become expansive through out the lake (Figure 6). Particularly in shallow lakes, such as Machado Lake, the combination of available nutrients and greater light intensity throughout the water column provides the light that is need for rapid plant growth. In addition, light can penetrate to the lake bottom promoting macrophyte growth. In comparison, in deep lakes a greater portion of the water column is not able to support photosynthesis as a majority of the water column is below is the light penetration depth. Thus, the impacts of nutrient loading and the biological response of algal blooms and dominant macrophytes is often very apparent in shallow lakes.

Plant growth can lead to increased pH in the lake due to rapid consumption of carbon dioxide. The elevated pH creates a harmful environment for organisms and can increase the concentration of ammonia potentially leading to direct toxicity of fish and other organisms. As these large phytoplankton populations and macrophytes die or break apart the decomposition process will consume oxygen and dramatically reduce the oxygen levels found in the lake. Low dissolved oxygen levels can become very stressful for fish and other organisms and may in fact lead to fish kills (Figure 6). Moreover, as the plant material is decomposed the nutrients are released and will recycle through the system. Shallow lakes tend to have increased biological productivity because it is likely that the photosynthetic zone and decomposition zone of the water column overlap, creating the situation in which as materials are decomposed and the nutrients released they are also immediately available for photosynthesis and plant growth continuing to drive ongoing impairments.

### 2.1.2 Lake Classification System

Lakes can be classified in many different ways; a common classification system is the trophic state. The trophic state of a lake is understood to be the biological response to nutrient additions. The relationship of chlorophyll levels and phosphorus concentrations in lakes has been studied in datasets worldwide and this relationship is used to define the trophic state of a lake (Wetzel, 2001). Lakes with low phosphorus and chlorophyll concentrations are considered oligotrophic, a classic example would be Lake Tahoe. Lakes with high phosphorus and chlorophyll concentrations would be considered eutrophic. Carlson (1977) developed a simple production based trophic state index (TSI) to classify and describe lakes. The TSI uses algal biomass as the basis for trophic state classification. The TSI is a convenient way to quantify the relationship between nutrients and algal biomass based on three independent variables: Secchi depth (transparency), chlorophyll *a* and total phosphorus. Carlson's index utilizes the log transformation of Secchi depth measurements; each 10 unit division represents a halving or doubling of the Secchi depth. Because chlorophyll *a* and total phosphorus are usually closely correlated to Secchi disk measurements, these parameters can also be assigned trophic state index values. The Carlson indices are relatively easy to calculate, the simplified equations are listed below.



$$\text{TSI (SD)} = 60 - 14.41 \ln \text{SD} \tag{1}$$

$$\text{TSI (CHL)} = 9.81 \ln \text{CHL} + 30.6 \tag{2}$$

$$\text{TSI (TP)} = 14.42 \ln \text{TP} + 4.15 \tag{3}$$

The Carlson trophic state indices are commonly used to define a lake's trophic state. The following table of the Trophic State Index generally relates lake characteristics and is used to interpret the TSI.

**Table 1. Description of possible characteristics and changes in lake water quality as the TSI increases**

| Trophic State | TSI | Chlorophyll (µg/L) | SD (m) | TP (µg/L) | Characteristics | Fisheries and Recreation |
|---|---|---|---|---|---|---|
| Oligotrophic | < 30 | <0.95 | > 8 | <6 | Clear water, oxygen throughout the year in the hypolimnion | Salmonid fisheries dominate |
| Oligotrophic | 30 – 40 | 0.95 - 2.6 | 8 – 4 | 6 –12 | Hypolimnion of shallower lakes may become anoxic | |
| Mesotrophic | 40 – 50 | 2.6 – 7.3 | 4 – 2 | 12 – 24 | Water moderately clear; increasing probability of hypolimnetic anoxia during summer | Hypolimnetic anoxia results in loss of salmonids |
| Eutrophic | 50 – 60 | 7.3 – 20 | 2 – 1 | 24 – 48 | Anoxic hypolimnia, macrophyte problems possible | Warm-water fisheries only, bass may dominate |
| Eutrophic | 60 – 70 | 20 – 56 | 0.5 – 1 | 48 – 96 | Blue-green algae dominate, algal scums and macrophyte problems | Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating |
| Hyper-Eutrophic | 70 – 80 | 56 – 155 | 0.25 – 0.5 | 96 – 192 | Light limited productivity Dense algae and macrophytes | |
| Hyper-Eutrophic | >80 | >155 | <0.25 | 192 – 384 | Algal scums, few macrophytes | Rough fish dominate |

Adopted from Carlson, R.E. and Simpson, 1996

Fisheries may be expected to vary with latitude and altitude

In addition to the three original indices Kratzer and Brezonik (1981) developed a TSI index for total nitrogen. This index was designed to be used in nitrogen limiting conditions under which nitrogen would be a better predictor of algal biomass than phosphorus. The index is calculated using the following formula.

$$TSI\ (TN) = 54.45 + 14.43\ \ln(TN) \qquad (4)$$

Employing a lake classification system such as the TSI is a meaningful and practical way to explore the relationships between variables and understand the nature of the lake. For example, identifying what factors may be driving algal biomass growth and influencing water quality in the lake can lead to effective management measures.

When identifying a lake's trophic state, staff does not automatically consider the trophic state classification equivalent to the water quality conditions. Although the concepts are similar and related, they should not be used interchangeably. The trophic state of a lake describes the biological condition of the lake and is not subject to change based the preference of the observer or use of the waterbody (Carlson, 1996). The trophic states have fixed descriptive characteristics and within each state there is a range of characteristics. This is opposed to the concept of water quality, which does not have fixed characteristics, but rather could be good or poor depending on the observer or use of the waterbody (Carlson, 1996). For example, an oligotrophic lake that does not support an aquatic macrophyte community could be considered poor water quality to support a large mouth bass sport fishery, but good water quality for a fishery of lake trout.

## 2.2 Machado Lake Problem Statement

The most distinct water quality problem affecting Machado Lake is eutrophication. The eutrophic condition arises due to the enrichment of the lake with nutrients (nitrogen and phosphorus). The nutrient enrichment results in high algal productivity; algal blooms have been observed in the lake during summer months. In addition, high nutrient concentrations contribute to excessive and nuisance macrophyte growth. Algae respiration and decay depletes oxygen from the water column creating an adverse aquatic environment. Likewise, the decay of algal blooms and other eutrophic related impairments can create offensive odors leading to an unpleasant environment. This alteration of the ecosystem degrades warm water habitat leading to impaired Warm Freshwater Habitat (WARM), Water Contact Recreation (REC 1), and Non-contact Water Recreation (REC 2) beneficial uses of Machado Lake. As a result of high nutrient concentrations, algal blooms, odors and eutrophic conditions Machado Lake was placed on the Clean Water Act 303(d) list of impaired waterbodies in 1998, 2002, and 2006.



## 2.3 Water Quality Standards

California water quality standards consist of the following elements: 1) beneficial uses, 2) narrative and/or numeric water quality objectives, and 3) an antidegradation policy. In California, beneficial uses are defined by the regional boards in their Water Quality Control Plans (Basin Plans). Numeric and narrative objectives are designed to be protective of the beneficial uses specified in the Water Quality Control Plan Los Angeles Region (Basin Plan).

### Beneficial Uses

The Basin Plan (1994) defines seven beneficial uses for Machado Lake (Table 2). These uses are recognized as existing (E), potential (P) or intermittent (I) uses. Nutrient loading to Machado Lake may result in impairments of beneficial uses associated with recreation (REC 1 and REC 2), aquatic life (WARM, WILD, RARE, and WET). The municipal supply (MUN) use designation applies to Machado Lake as a potential beneficial use. This beneficial use, for Machado Lake, is indicated with an asterisk in the Basin Plan as a conditional use. Conditional designations are not recognized under federal law and are not water quality standards requiring TMDL development at this time. (See Letter from Alexis Strauss [USEPA] to Celeste Cantú [State Board], Feb. 15, 2002.)

**Table 2 Beneficial uses of Machado Lake. (LARWQCB, 1994)**

| Reach | MUN | REC 1 | REC 2 | WARM | WILD | RARE | WET |
|---|---|---|---|---|---|---|---|
| Machado Lake | P* | E | E | E | E | E | E |

WATER QUALITY OBJECTIVES

The Basin Plan (1994) specifies narrative and numeric objectives, which both apply to Machado Lake. The following narrative objectives are most pertinent to the nutrient TMDL.

D R A F T

Biostimulatory Substances: *Waters shall not contain biostimulatory substances in concentrations that promote aquatic growth to the extent that such growth causes nuisance or adversely affects beneficial uses.*

Taste and Odor: *Waters shall not contain taste or odor-producing substances in concentrations that impart undesirable tastes or odors to fish flesh or other edible aquatic resources, cause nuisance, or adversely affect beneficial uses.*

The numeric objectives which apply to Machado Lake are listed below:

Dissolved Oxygen (DO): *At a minimum the mean annual DO concentrations of all waters shall be greater than 7.0 mg/L, and no single determinations shall be less than 5.0 mg/L except when natural conditions cause lesser concentrations. The dissolved oxygen content of all surface waters designated as WARM shall not be depressed below 5 mg/L as a result of waste discharges*

This numeric objective will be applied to Machado Lake.

Ammonia: *In order to protect aquatic life, ammonia concentrations in inland surface waters characteristic of freshwater shall not exceed the values calculated for the appropriate instream conditions shown in Tables 3-1 – 3-3.*

Numeric objectives for ammonia are protective of fish (COLD), (WARM) and wildlife (WILD) (see Basin Plan Tables 3-1 through 3-4). The objective for chronic exposure is based on a four-day average concentration. The objective for acute toxicity is based on a one-hour average concentration. These objectives are expressed as a function of pH and temperature because un-ionized ammonia ($NH_3$) is particularly toxic to fish and other aquatic life.

Nitrogen: *Waters shall not exceed 10 mg/L nitrogen as nitrate-nitrogen plus nitrite-nitrogen ($NO_3$-N + $NO_2$ – N), 45 mg/L as nitrate ($NO_3$), 10 mg/L as nitrate-nitrogen ($NO_3$-N) or 1 mg/L as nitrite-nitrogen ($NO_2$-N).*

Based on review of an extensive body of technical literature, Regional Board staff concluded that the numeric nitrogen objective will not support the biostimulatory substance narrative water quality objective in the Basin Plan. A review of available data and scientific literature demonstrates that the numeric objective of 10 mg/L for nitrogen is not sufficiently protective for controlling excessive algal growth and eutrophic conditions in the lake. Therefore, this TMDL sets the numeric target for total nitrogen less than the water quality objective of 10 mg/L listed in the Basin Plan in order to ensure attainment of the biostimulatory substance objective and protect beneficial uses.

Other Regional Boards in California have adopted nutrient TMDLs for lakes in which they relied upon narrative water quality objectives, and in interpreting these narrative objectives, set TMDL numeric targets that were more stringent than existing numeric nutrient water quality objectives in the their Basin Plans. These Regions relied upon the narrative Biostimulatory Substances objective. Table 3 below lists Regions and TMDLs in which this was done.



**Table 3. Lake Nutrient TMDLs in other Regions**

| Region | TMDL | Final Numeric Targets | | | |
|---|---|---|---|---|---|
| | | Total P (mg/L) | Total N (mg/L) | Chl. a (ug/L) | DO (mg/L) |
| 5 | Clear Lake Nutrient TMDL | 87,100 kg (loaded annually) | No Target | 73 instantaneous maximum | No Target |
| 6 | Indian Creek Reservoir Phosphorus TMDL | 0.02 | No Target | 14 | 7 or no less than 10% of 80% saturation |
| 8 | Lake Elsinore and Canyon Lake Nutrient TMDLs | 0.05 | 0.5 | 25 | 5 (1 meter above the sediments) |
| 8 | Nutrient TMDL for Big Bear Lake | 0.02 | 1.0 | 5 | No Target |

The TMDLs for eutrophic conditions, algae, ammonia, and odors in Machado Lake are based on the Biostimulatory substances, Dissolved Oxygen, and Ammonia water quality objectives in the Basin Plan for the protection of beneficial uses. The biostimulatory substances objective simply requires that waters not contain biostimulatory substances (nitrogen and phosphorus) in concentrations that will promote excessive plant growth. The numeric targets of the TMDL will establish concentrations for total nitrogen and total phosphorus in Machado Lake that attain the biostimulatory substances objective. The numeric targets and allocations for total nitrogen and phosphorus will address the listings of eutrophic, algae, and odors.

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#### ANTIDEGRADATION

State Board Resolution 68-16, "Statement of Policy with Respect to Maintaining High Quality Water" in California, known as the "Antidegradation Policy," protects surface and ground waters from degradation. Any actions that can adversely affect water quality in all surface and ground waters must be consistent with the maximum benefit to the people of the state, must not unreasonably affect present and anticipated beneficial use of such water, and must not result in water quality less than that prescribed in water quality plans and policies. Furthermore, any actions that can adversely affect surface waters are also subject to the federal Antidegradation Policy (40 CFR 131.12). The proposed TMDL will not degrade water quality, and will in fact improve water quality as it is designed to achieve compliance with existing water quality standards.

### 2.4 WATER QUALITY DATA SUMMARY

This section presents a review of the data used by the Los Angeles Regional Board to list Machado Lake for eutrophic, algae, odors, and ammonia. Additional data, where available, were also used to assess the current condition of the lake.

Machado Lake (previously known as Harbor Park Lake) was included in the 1992-93 Evaluation of Water Quality for Selected Lakes in the Los Angeles Hydrologic Basin, the lake was sampled 15 times as part of this evaluation. Staff was unable to locate a 1998 Machado Lake fact sheet, but assumes that the data from this monitoring program were used for the original 303 (d) listing in 1998. A review of these data shows elevated nutrient levels; total phosphorus ranged from 0.2 to 1.0 mg/L and total nitrogen ranged from 0.3 to 2.9 mg/L. The chlorophyll *a* concentration ranged from 7 - 47 ug/L, with the average concentration reported as 19 ug/L. The Secchi depth appeared to range from 1.0 -1.6 meters. The Carlson TSI was calculated based on Secchi depth, chlorophyll, and total phosphorus and returned results of 68, 58, and 94 respectively. When these TSI values are interpreted based on Table 1 the lake would be identified as eutrophic to hypereutrophic. The dissolved oxygen concentration in 1992-93 was always greater than 5 mg/L; although at this time the lake was reported to have an operational aeration system, which would have prevented stressful low dissolved oxygen conditions. At the time of this evaluation the lake depth was estimated to range from 1 – 3.5 meters.



The water quality at Machado Lake has generally declined during the 15 intervening years from the monitoring in 1992-93 to the monitoring conducted as part of the TMDL development from the summer of 2006 to the summer of 2007. The nutrient concentrations in the lake have increased; in 1992-93 the maximum TP concentration was 1 mg/L, and in 2006-07 the average concentration was approximately 1 mg/L with the maximum measured as 1.35 mg/L (Figure 7). The average dissolved phosphorus concentration in the lake is 0.71 mg/L.

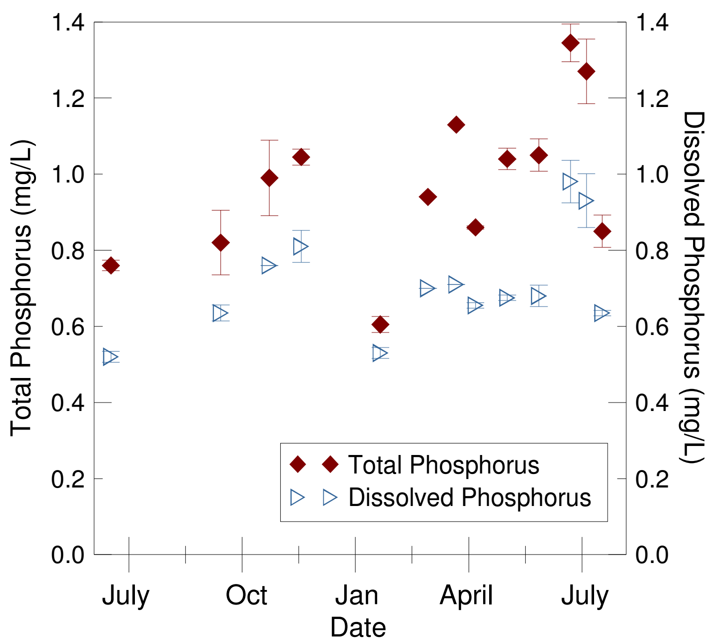


**Figure 7 Dissolved and total phosphorus concentration over time June 2006 - August 2007 (lake wide average)**

Similarly, the total nitrogen (TKN + $NO_3$-N + $NO_2$ –N) concentration in the lake has increased; the 2006-07 average concentration was 2.7 mg/L and the maximum measured concentration was 4.2 mg/L (Figure 8).

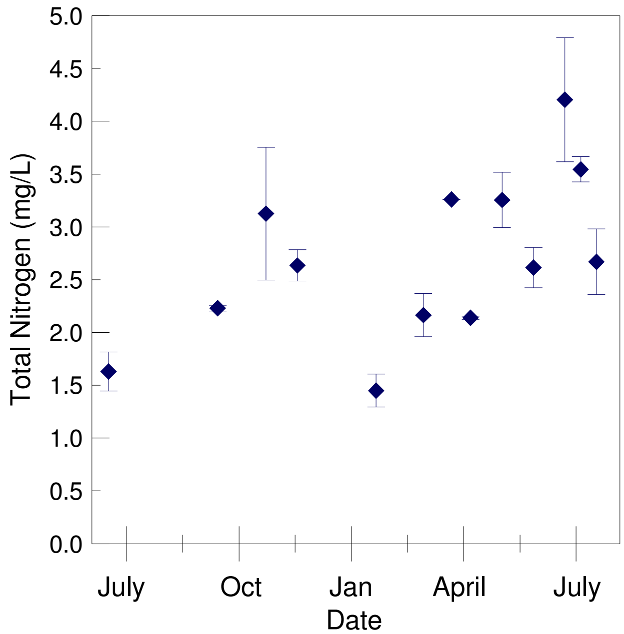


**Figure 8 Total Nitrogen concentration over time June 2006 - August 2007 (lake wide average)**

The results of ammonia samples collected at the lake from summer 2006 through summer 2007 are shown in Table 4. The ammonia concentration was generally below the method reporting limit of 0.1 mg/L. Three sampling events had measurable amounts of ammonia with concentrations ranging from 0.14 – 0.56 mg/L.

**Table 4 Machado Lake ammonia concentrations**

| Date | $NH_3$ - N (mg/L) |
|---|---|
| June 19, 2006 | BRL |
| September 21, 2006 | BRL |
| November 3, 2006 | BRL |
| December 1, 2006 | 0.56 |
| February 9, 2007 | BRL |
| March 23, 2007 | BRL |
| April 16, 2007 | BRL |
| May 5, 2007 | BRL |
| June 1, 2007 | 0.14 |
| June 29, 2007 | BRL |
| July 27, 2007 | BRL |
| August 10, 2007 | 0.25 |
| August 24, 2007 | BRL |
| BRL (Below Reporting Limit) | |

The Secchi depth has reduced to an annual average of 0.36 meters and the chlorophyll concentration has increased to 87 µg/L (average spring/summer 2007). Table 5 presents the chlorophyll *a* concentrations measured in the lake in 2007. As expected, summer concentrations are high with the maximum observed at 131 µg/L and concentrations reduce in the winter as light and temperature decline.

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**Table 5 Machado Lake chlorophyll *a* concentrations measured in 2007**

| Date | Chlorophyll *a* (µg/L) |
|---|---|
| March 23, 2007 | 78 |
| April 17, 2007 | 73 |
| May 4, 2007 | 45 |
| June 1, 2007 | 129 |
| July 27, 2007 | 131 |
| August 10, 2007 | 74 |
| August 24, 2007 | 80 |
| October 19, 2007 | 36 |
| November 2, 2007 | 29 |

There were 26 dissolved oxygen profiles measured at the lake from summer 2006 to summer 2007. Sampling events were in the morning with data collected at approximately 9:00 am. At six of these sampling events the entire water column had less than 5mg/L dissolved oxygen. Figure 9 is a representative a dissolved oxygen profile from the lake with DO concentrations of less than 5 mg/L.

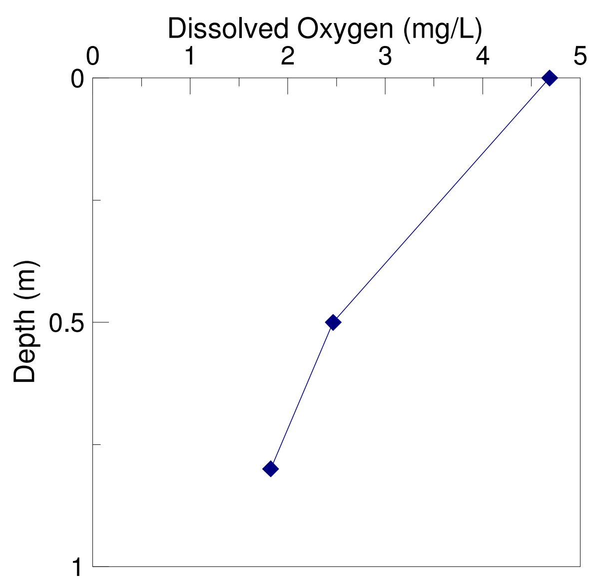


**Figure 9 Machado Lake dissolved oxygen profile measured on July 27, 2007**

In addition, there were instances where the surface water (< 0.5 m) demonstrated super saturation and oxygen at greater depths (0.5 – 1.5) was quickly depleted (Figure 10).

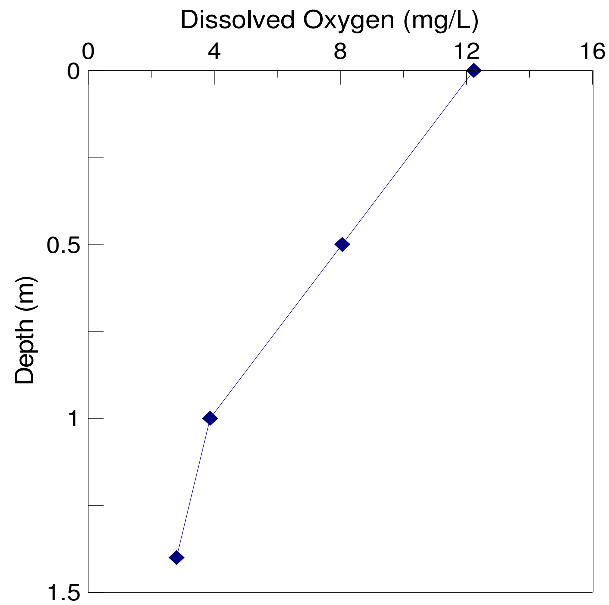


**Figure 10 Machado Lake dissolved oxygen profile measured on July 7, 2006**

Table 6 presents a summary of the temperature and pH data collected at the lake. The temperature and pH data is used to calculate the ammonia Criteria Continuous Concentration (CCC) and Criteria Maximum Concentration (CMC) presented in the numeric targets section.

**Table 6 Machado Lake summary of temperature and pH data**

| Statistical Parameter | Temperature ($^{o}$C) | pH |
|---|---|---|
| Maximum | 26.76 | 8.50 |
| Minimum | 12.47 | 7.10 |
| Mean | 20.98 | 7.73 |
| Median | 22.48 | 7.76 |
| St.Dev | 4.52 | 0.33 |
| 95th Percentile | 26.13 | 8.18 |

An important factor currently impacting water quality is the loss in lake level since the 1992-93 evaluation. The monitoring conducted as part of TMDL development showed a depth range of <0.5 - 1.5 meters with an average depth of approximately 1 meter. This very low lake level complicates many physical and biological processes in the lake.

# 3 NUMERIC TARGETS



Machado Lake is 303(d) listed for eutrophic, algae, ammonia, and odors. These listings are caused by exceedances of the narrative Biostimulatory Substances (phosphorus and nitrogen) objective and the resultant eutrophic conditions. The characteristics of eutrophic conditions include excessive algal and macrophyte growth and low dissolved oxygen concentrations. The chemical pollutants that most stimulate excessive aquatic vegetative growth and stimulate eutrophication are nitrogen and phosphorus, thus numeric targets will be set for these constituents in this TMDL. Indicators and targets for parameters other than phosphorus and nitrogen are also established in order to track the symptoms of eutrophication and improvements in water quality. These targets include dissolved oxygen and chlorophyll *a*. Machado Lake is listed for an algae impairment, so chlorophyll *a*, a measurement of algal biomass, is an appropriate target for this listing. Chlorophyll *a* will gauge the biological response of the lake to nutrient loads and is closely tied to the public perception of lake water quality. Dissolved oxygen will also serve as a measure of Machado Lake's response to nutrient loads. An ammonia target will also be set to ensure the lake continues to meet the ammonia objectives in the Basin Plan and not contribute to excessive levels of nitrogen.

Regional Board staff interpreted the narrative biostimulatory substances water quality objective in the Basin Plan and concluded that the existing numeric nitrogen objective is not supportive of the narrative biostimulatory substance water quality objective. The nitrogen objective (10 mg/L) in the Basin Plan is based on criteria acceptable for drinking water and not appropriate to address eutrophic conditions in the lake. A review of available data and scientific literature demonstrates that the numeric objective of 10 mg/L for nitrogen is not sufficiently protective for controlling excessive algal/macrophyte growth and the symptoms of eutrophication in the lake. Therefore, the numeric target for total nitrogen will be more stringent than the existing numeric nitrogen objective in the Basin Plan to ensure attainment of the narrative biostimulatory substances water quality objective. The TMDL and its numeric targets must be developed to ensure protection of all the beneficial uses and attainment of nutrient related water quality objectives specified in the Basin Plan.

Regional Board staff assessed various alternatives for the establishment of total nitrogen and total phosphorus, and chlorophyll *a* numeric targets, such as established literature values, classification systems, EPA Guidance, and the reference state approach. Staff did not conclude that selecting values solely based on established literature values was appropriate for Machado Lake. Likewise, it was not appropriate to select a reference state because there is not a similar water body in the area that is unimpaired.

To set the numeric targets for Machado Lake staff relied upon the proven strong relationship between total phosphorus, total nitrogen, and chlorophyll *a* concentrations. Since, it is well established in the scientific literature that nitrogen and phosphorus play a pivotal role in the growth of algal biomass and macrophytes, staff first determined the target for chlorophyll *a* as a measure of algal biomass. To make this determination staff relied upon a classification system, the Carlson Trophic State Index, EPA guidance for the development of nutrient TMDLs, and the measured chlorophyll *a* data collected from Machado Lake. A numeric target of 20 ug/L chlorophyll *a* is established to protect the beneficial uses of Machado Lake based on EPA guidance (EPA, 1999). This value is expected to protect the aquatic life beneficial uses and typical recreational activities such as, boating, swimming, viewing pleasure, and fishing. This value was compared to Carlson Trophic State Index classification system to approximate the potential water quality characteristics associated with this chlorophyll concentration. It is anticipated at this level the lake will not show the extremely negative symptoms of eutrophication such as, blue green algal blooms, invasive and nuisance macrophyte growth, and light limitation. The measured chlorophyll *a* data from Machado Lake was considerably greater than reported literature values of acceptable levels of chlorophyll *a;* therefore, it was not considered as the basis for a chlorophyll numeric target.

The relationship between total nutrients and chlorophyll *a* in Machado Lake was analyzed by using the Nutrients Numeric Endpoints (NNE) BATHTUB spreadsheet tool. The NNE tools were developed by Tetra Tech with support by US EPA Region IX and the State Water Resources Control Board. The BATHTUB spreadsheet tool is a user friendly arrangement of the Army Corps of Engineers BATHTUB model (Walker, 1987, 1996) used to analyze the response of lake water quality to different nutrient loading situations. Tetra Tech configured the BATHTUB model to be used in an excel spreadsheet format. The water quality conditions of the lake are predicted based on relationships developed and tested from a wide range of lakes. The NNE BATHTUB spreadsheet model was used as part of this TMDL to scope the appropriate numeric targets and to calculate loading capacity. For additional information on the NNE BATHTUB spreadsheet model, including model calibration, application, and sensitivity analysis, see the Technical Memo for Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL (Lai, 2007)



The BATHTUB spreadsheet tool allows the user to input a target chlorophyll *a* value and the program will calculate the corresponding nitrogen and phosphorus loads to meet this target. The loading calculations are not only based upon the empirical relationship between algal biomass and nutrients but physical parameters of the lake such as lake volume, surface area, depth, mixing depth, and inflow. The NNE BATHTUB tool successfully predicted the water quality situation in Machado Lake (Lai, 2007).

A review of the NNE BATHTUB tool was conducted by comparing the NNE predicted values and measured values of data from Machado Lake during the summer growing season for the following constituents: chlorophyll *a*, median Secchi depth, total phosphorus concentration and total nitrogen concentration. The table below shows both the measured and predicted growing season water quality results for Machado Lake (Table 7).

There is good agreement between the NNE predicted and measured results for the average chlorophyll *a*, median Secchi depth, total phosphorus, and total nitrogen concentrations with a Relative Percent Difference (RPD) of 2, 0, 7 and 15 percent, respectively. The widest discrepancy found between measured and predicted data was for total nitrogen; the NNE under predicted the TN concentration by about 15 percent. The reason for this discrepancy is not entirely clear, although it is expected that if the model were calibrated with respect to TN the measured and predicted results would have better agreement. Nevertheless, the total nitrogen results were not considered to undermine the modeling efforts. In general the model was successful in predicting the water quality of Machado Lake.

**Table 7 NNE predicted and measured growing season water quality**

| Growing Season - Summary Results based on annual nutrient loading | | | |
|---|---|---|---|
| | NNE Result | Measured Data | Relative Percent Difference |
| Avg. Chl a (ug/L) | 89.8 | 91.8 | 2 |
| Median Secchi Depth (cm) | 0.3 | 0.3 | 0.0 |
| TP (mg/L) | 1 | 1.07 | 7 |
| TN (mg/L) | 2.6 | 3.07 | 15 |

Based on the good agreement of predicted and measured values for total phosphorus, total nitrogen, chlorophyll *a*, and Secchi depth the NNE BATHTUB tool proved to be a valuable tool in evaluating the water quality of Machado Lake.

Staff also reviewed the EPA Nutrient Criteria Technical Guidance Manual Lakes and Reservoirs (2000), which does not recommend setting a numeric target for total phosphorus greater than 0.1 mg/L. This guidance was relied upon for setting the numeric phosphorus and nitrogen numeric targets for Machado Lake. The phosphorus target is established as 0.1 mg/L as a monthly average concentration in the water column. To maintain a balance of nutrients for biomass growth and prevent limitation by one nutrient or another, a ratio of total nitrogen to total phosphorus of 10 is used to derive the total nitrogen numeric target of 1.0 mg/L as a monthly average concentration (Thomann, Mueller, 1987).

Table 8 provides a summary of the numeric targets for Machado Lake. Because ammonia–N is inherently linked to total nitrogen concentrations as a form of nitrogen, the numeric targets for these two constituents are also linked. Figure 11 presents the Basin Plan Ammonia CCC and CMC, calculated at the median temperature and pH values of the lake (Table 6), as 2.15 mg/L and 5.95 mg/L, respectively. An ammonia numeric target is set at 5.95 mg/L as a water column hourly average to be protective of acute aquatic life exposure. The total nitrogen (TKN + $NO_3$-N + $NO_2$ –N) target shall be 1.0 mg/L as a water column monthly average. Since the total nitrogen target includes nitrogen in the form of ammonia, and the value is more conservative than the Basin Plan ammonia – N objective for aquatic life chronic exposure, it will also be protective of aquatic life for ammonia toxicity (Figure 11). The chlorophyll *a* target is set as 20 ug/L based on EPA guidance and a review of the Carlson Trophic Status Index. The dissolved oxygen target is a concentration of no less than 5 mg/L measured at 0.3 meter above the sediments based on the Basin Plan objective.



**Table 8 Numeric Targets for Machado Lake Nutrient TMDL**

| Indicator | Numeric Target | Reference |
|---|---|---|
| Total Phosphorus | 0.1 mg/L monthly average | EPA Guidance 2000 |
| Total Nitrogen (TKN + $NO_3$-N + $NO_2$ –N) | 1.0 mg/L monthly average | EPA Guidance 2000 |
| Ammonia | 5.95 mg/L hourly average | Basin Plan |
| Dissolved Oxygen | 5 mg/L single sample minimum measured 0.3 meter above the sediments. | Basin Plan |
| Chlorophyll *a* | 20 ug/L monthly average | EPA Guidance 1999 and review of Carlson Trophic State Index Classification System |

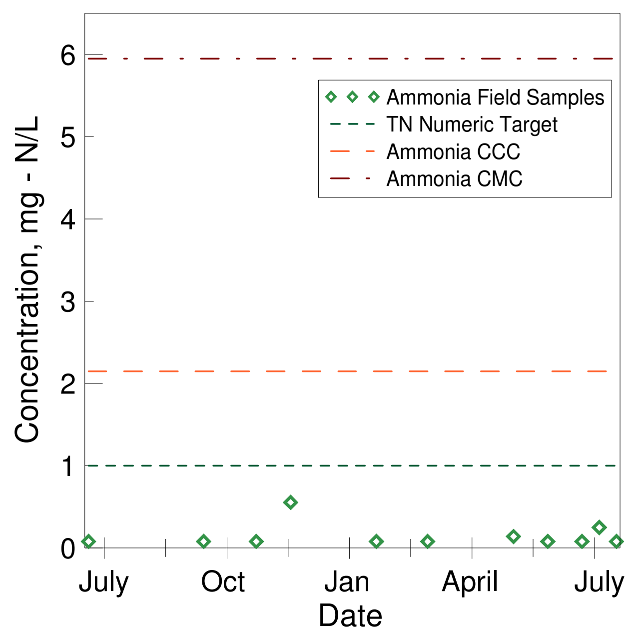


**Figure 11 Machado Lake measured ammonia concentration, ammonia water quality objectives, and TN numeric target**

# 4 SOURCE ASSESSMENT

This section identifies the potential sources of nutrients in the Machado Lake subwatershed. In the context of TMDLs pollutant sources are either point sources or nonpoint sources. Point sources include discharges for which there are defined outfalls such as wastewater treatment plants and storm drain outlets. The point source discharges are regulated through the National Pollutant Discharge Elimination System (NPDES) permits. Nonpoint sources, by definition include pollutants that reach waters from a number of diffuse landuses and source activities that generate runoff in the lake and are not regulated through NPDES permits.



## 4.1 POINT SOURCES

The NPDES permits in the Machado Lake subwatershed include the Los Angeles County municipal separate storm sewer system (MS4) permit, the Caltrans stormwater permit, and general industrial stormwater permits. A summary of the NPDES permits with discharges to Machado Lake are presented below in table 9.

**Table 9 Summary of Los Angeles Regional Board issued NPDES permits in the Machado Lake subwatershed.**

| Type of Discharge | Total Permits |
|---|---|
| Municipal Stormwater | 1 |
| Caltrans Stormwater | 1 |
| Industrial Stormwater | 37 |

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### 4.1.1 STORMWATER PERMITS

MS4 STORMWATER PERMITS

In 1990 EPA developed rules establishing Phase 1 of the NPDES stormwater program, designed to prevent pollutants from being washed by stormwater runoff into the MS4 (or from being directly discharged into the MS4) and then discharged into local waterbodies. Phase 1 of the program required operators of medium and large MS4s (those generally serving populations of 100,000 or more) to implement a stormwater management program as a means to control polluted discharges. The Los Angeles County MS4 permit was renewed in December 2001 as Order No. R4-01-182 and is on a five year renewal cycle. The County of Los Angeles is the principal permittee and there are 85 co-permittees covered by this permit, including 84 incorporated cities and the County of Los Angeles. The co-permittee cities in the Machado Lake sub-watershed include the following:

- City of Carson
- City of Lomita
- City of Los Angeles
- City of Palos Verdes Estates
- City of Rancho Palos Verdes
- City of Redondo Beach
- City of Rolling Hills
- City of Rolling Hills Estates
- City of Torrance

CALTRANS STORMWATER PERMIT

Discharges from roadways under the jurisdiction of Caltrans are regulated by a statewide stormwater discharge permit that covers all municipal stormwater activities and construction activities (State Board Order No. 99-06-DWQ). The Caltrans stormwater permit authorizes stormwater discharges from Caltrans properties such as the state highway system, park and ride facilities, and maintenance yards. The stormwater discharges from most of these Caltrans properties and facilities eventually end up in a municipal storm drain, which then discharges to Machado Lake.



GENERAL STORMWATER PERMITS

In 1990 EPA issued regulations for controlling pollutants in stormwater discharges from industrial sites (40 CFR Parts 122, 123, and 124) equal to or greater than five acres. The regulations require discharges of stormwater associated with industrial activity to obtain an NPDES permit and to implement Best Available Technology Economically Achievable (BAT) to reduce or prevent pollutants associated with industrial activity. On April 17, 1997, the State Water Resources Control Board issued a statewide general NPDES permit for Discharges of Stormwater Associated with Industrial Activities Excluding Construction Activities Permit (Order No. 97-03-DWQ, NPDES Permit Nos. CAS000001). As of the writing of the TMDL, there are approximately 37 discharges enrolled under the general industrial stormwater permit in the Machado Lake subwatershed. The State Water Resources Control Board issued a statewide general NPDES permit for Discharges of Stormwater Runoff Associated with Construction Activities (Order No. 99-08-DWQ, NPDES Permit Nos. CAS000002) on August 19, 1999. As of the writing of this TMDL, were no dischargers enrolled under the general construction stormwater permit in the Machado Lake subwatershed.

### 4.1.2 OTHER NPDES PERMITS

There are no Major Individual, Minor Individual, or General NPDES Permits adopted by the Regional Board for the Machado Lake subwatershed.

### 4.1.3 QUANTIFICATION OF EXTERNAL SOURCES FROM STORMDRAINS

The total external nutrient load from the surrounding watershed, entering the lake through stormdrains, was estimated by multiplying the concentration of the pollutant of concern, in this case total nitrogen and total phosphorus, and volume of runoff. The nitrogen and phosphorus concentrations used for this calculation were from the Los Angeles County Stormwater monitoring program mass emissions stations (1994 - 2005) mean of annual means. The annual runoff in the watershed was estimated based on the area of each stormdrain catchment, the ratio of imperviousness in the watershed and the 5 year annual average rainfall. On an annual basis 7,587 kg of total nitrogen and 3,260 kg of total phosphorus enters Machado Lake through the stormdrains. Table 10 shows the average annual nutrient load from each sub drainage.

**Table 10 Average annual external nutrient load to Machado Lake by sub drainage area**

| | Total N Load (kg) [a] | Total P Load (kg) [b] | Ortho-P Load (kg) [c] | Inorg-N Load (kg) [d] |
|---|---|---|---|---|
| Drain 553 | 4,039 | 1,706 | 402 | 2,010 |
| Wilmington Drain | 2,043 | 886 | 195 | 999 |
| Project 77/510 | 898 | 390 | 84 | 436 |
| Walteria Lake | 607 | 278 | 56 | 292 |
| **Total** | **7,587** | **3,260** | **737** | **3,736** |

The area of each sub-drainage was obtained from the Machado Lake Watershed Management Plan prepared by Parsons for City of Los Angeles, Department of Recreation and Parks, May, 2002. A review of the maps of the stormdrain network show that discharges from Walteria Lake and Drain 553 do not directly discharge to the lake. They are tributary to the Wilmington Drain, which then directly discharges in the northern portion of Machado Lake. Approximately, 88 % of the discharge into the lake enters through the Wilmington Drain.

## 4.2 NONPOINT SOURCES

### 4.2.1 INTERNAL NUTRIENT LOADING

As previously discussed in the problem identification section, nutrients are recycled in lakes and a process for internal nutrient recycling (internal loading) is the exchange of nutrients across the sediment water interface. A sediment core flux study was conducted by Southern California Coastal Water Research Project (SCCWRP) for Machado Lake to estimate the flux rate of ammonia, nitrate, and phosphate from the sediments. The experiment conducted was an initial range finding experiment to assess potential maximum flux rates and to determine if in fact the sediments of Machado Lake are a nutrient source of concern.

Sediment cores were collected from the center of Machado Lake and then incubated in the laboratory under oxic conditions at 15 ºC and 25 ºC to simulate summer and winter temperature conditions. Reconstituted laboratory water was added to the top of each core. The goal of the experiment was to estimate potential maximum nutrient flux; therefore, by using the reconstituted laboratory water, a nutrient poor water source, a strong concentration gradient was created between the sediment and the overlying water. This strong concentration gradient created a situation in which the sediment nutrient flux is at the maximum potential. For each temperature regime, triplicate water samples were collected at different time intervals ($T_4$, $T_8$, $T_{12}$, $T_{24}$, $T_{48}$, $T_{96}$) over 96 hours and analyzed for nitrogen and phosphorus species.



Flux rates were calculated in mg/m$^2$/hr by multiplying each nutrient concentration (mg/L) by the water volume for each core (600 mL), then dividing by the surface area of the core tube (0.0031 m$^2$), and then dividing by the total exposure time in hours. The results for $T_4$- $T_{96}$ were averaged ($\pm$ 95% CI) for each temperature group. The results are presented in Table 11 below.

**Table 11 Average flux rate of sediment cores**

| | | Flux (mg/m$^2$/hr) | | | |
|---|---|---|---|---|---|
| **Temp** | **Sample Size** | **$NH_3$-N** | **$NO_3$-N** | **Dissolved $PO_4$-P** | **Total $PO_4$-P** |
| 15°C | 24 | 11.7 $\pm$ 6.4 | 1.9 $\pm$ 0.9 | 3.4 $\pm$ 1.6 | 4.9 $\pm$ 2.3 |
| 25°C | 21 | 7.9 $\pm$ 4.7 | 1.8 $\pm$ 0.9 | 3.6 $\pm$ 1.4 | 5.2 $\pm$ 2.0 |

These results were extrapolated to the entire lake area to estimate both seasonal (summer and winter) and annual nutrient mass load fluxing from the sediments (Table 12). It was assumed that the internal nutrient release rate is constant. The Machado Lake Watershed Management Plan sediment analysis reports that most of the lake bottom is covered by similar sediment types of surficial mud underlain by clay. This spatial homogeneity of the sediments supports the general assumption of uniform nutrient release rates. It is recommended that assumptions made as part of this initial experiment be verified or refined with special studies as part of the TMDL implementation plan.

Table 12 Estimated seasonal and annual internal nutrient mass load

| | May – Oct. Mass Load | Nov. – April Mass Load | Annual Internal Mass Load |
|---|---|---|---|
| | kg | kg | kg |
| $NH_3$-N | 5,601 | 8,295 | 13,896 |
| $NO_3$-N | 1,276 | 1,347 | 2,623 |
| Dissolved $PO_4$-P | 2,552 | 2,410 | 4,963 |
| Total $PO_4$-P | 3,686 | 3,474 | 7,160 |

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### 4.2.2 WIND RESUSPENSION

Another method of nutrient recycling is wind re-suspension of sediment particles. Based on the field experience of Regional Board staff and the characterization of Machado Lake sediments, as documented by the Machado Lake Watershed Management Plan, the first layer of sediment in the lake is a loose, unconsolidated, black, organic rich, surficial mud material. This surficial mud layer occurs from the surface grade of the sediments to 0.5 – 1.0 foot below surface grade and covers most of the lake bottom. This type of material could easily be re-suspended in the water column. Equations 1 and 2 presented in the Problem Identification section were used to estimate the critical depth at which Machado Lake sediments may potentially be resuspended under typical wind speeds and critical lake levels.

The wind-mixed depth (critical depth), taken as one-half the wavelength, L (Martin and McCutcheon, 1999), was calculated for the wind speeds of 1, 3.7, 2.8, and 10 m/s assuming a 450 meter fetch. A review of wind speed and direction data from a nearby weather station (Port of LA Wilmington weather station) shows that the wind regularly blows out of the south south-east across the lake approximately 450 meters. The wind speeds of 1 and 3.7 m/s represent the typically daily range of wind speeds often found at the lake, while 2.8 m/s represents typical afternoon wind speed, which is often sustained for several hours. The wind speed of 10 m/s is evaluated to represent storms, Santa Ana winds, or other unique weather conditions.

**Table 13 Predicted wave properties as a function of wind speed (fetch 450 m)**

| Wind Speed (m/s) | Wave Period (s) | Wavelength (m) | Critical Depth (m) |
|---|---|---|---|
| 1 | 0.43 | 0.29 | 0.14 |
| 3.7 | 0.9 | 1.25 | 0.63 |
| 2.8 | 0.77 | 0.93 | 0.46 |
| 10 | 1.51 | 3.54 | 1.77 |



Table 13 shows predicted wave properties as a function of wind speed. Under the very low wind speed of 1 m/s, sediment resuspension due to wave action is only expected in areas with a depth of approximately 0.14 meters. At Machado Lake it is unlikely that this wind speed (1 m/s) would cause significant sediment resuspension, due to the very shallow critical depth and because the macrophyte community is established in the lake within the range of this depth. The rooted macrophytes will serve to help hold the sediment in place and prevent resuspension at this shallow depth. However, as the wind speed increases to 3.7 and 2.8 m/s, the critical depth for resuspension also increases to 0.63 and 0.46 meters, respectively. When these depths are considered in relation to lake depth under critical conditions (average depth of 0.84 meters, summer 2007) it seems likely that areas of the lake would be subject to sediment resuspension. The strong wind speed of 10 m/s, possible under unique weather conditions, has a critical depth of 1.77 meters.

The area of the bottom sediments that is potentially subject to resuspension will vary strongly depending on the lake level. There is considerably less potential for resuspension at higher lake levels and the potential for extensive resuspension at very low lake levels. Updated bathymetric data for Machado Lake would be very useful in making precise estimations of the likelihood of sediment resuspension at the lake. Yet, the general analysis presented here does show a reasonable potential for resuspension to occur, especially under the summer critical conditions when the lake level is reduced due to evaporative processes.

Machado Lake may also be subject to sediment resuspension events during large storm events. The size and depth of Machado Lake, relative to its watersheds, creates a situation where turbulent stormwater flows discharged to the lake will likely disturb lake sediments causing turbid conditions due to sediment resuspension in the water column.

### 4.2.3 BIOTURBATION

Fish can also have an impact on nitrogen and phosphorus cycling and resuspension in lakes. In particular, the activities of bottom feeding fish such as carp can increase the movement of nitrogen and phosphorus from the sediments to the overlying water column (Wetzel, 2001). Generally, it is the feeding activity of the benthic fish that disturb the sediments and release nitrogen and phosphorus into the water. Studies addressing the impacts of benthic fish, carp in particular, on sediment and nutrient concentrations have shown significant positive relationships ($P<0.01$) between the amount of carp biomass and the amount of sediment collected in sediment traps and total suspended solids in the water column ($P<0.05$) (Breukelaar, 1994). This same study also demonstrated a significant positive relationship ($P<0.01$) between benthic fish biomass and total nitrogen concentrations. Additionally, bream (a benthivorous fish) was shown to cause a 0.03 mg/L increase in total phosphorus per 100 kg of bream per hectare (Breukelaar, 1994). Similarly, a study by Persson and Svensson (2006) showed increased concentrations of nitrogen and phosphorus in the water column of field enclosures with benthivorous fish than control field enclosures with no fish.

A comprehensive fish population survey has not been conducted for Machado Lake. However, the California Department of Fish and Game (CDFG) conducted annual fish sampling at the lake as part of the Toxic Substances Monitoring Program (TSMP) from 1983 – 1997. The species collected over the years included goldfish, carp, largemouth bass, bullhead and channel catfish. CDFG has informally reported to Regional Board staff that in more recent sampling events carp is the most frequent fish species collected and largemouth bass are very infrequently collected or not collected at all. Also, fishermen at the lake generally comment that they have caught or are fishing for carp. There is an Office of Environmental Health Hazard Assessment (OEHHA) advisory against the human consumption of carp and goldfish from Machado Lake, due to elevated levels of DDT and chlordane. Due to the lack of specific fish population assessments for Machado Lake, the contribution of nutrients to the lake from fish activities is not quantified.

### 4.2.4 Birds

Waterfowl excretions have been identified in several studies as importing nitrogen and phosphorus to aquatic ecosystems. Generally, the nutrient additions from waterfowl can be extremely variable due to factors such as seasonal migration. It has been estimated that a mature Canadian goose can contribute approximately 0.49 grams of total phosphorus and 1.57 grams of nitrogen on a daily basis (Wetzel, 2001). Likewise estimates of nitrogen and phosphorus loadings in constructed wetlands in California showed maximum inputs by birds of 41.8 g of nitrogen and 16.8 g of phosphorus per bird per year (Andersen et al. 2003).

At Machado Lake there are a variety of birds and waterfowl that are often observed at the lake both as resident and migratory species. However, to date there have not been any specific bird counts to determine the potential nutrient loading from bird species on an annual or seasonal basis. It is expected that the contribution of nitrogen and phosphorus would be modest in relation to other nutrient sources. Although nutrient contribution from birds is not separately quantified, the contribution is included in the overall nutrient total nutrient concentration data collected in the lake.

### 4.2.5 Atmospheric Deposition

Atmospheric deposition is also a potential source of nitrogen to the lake. It has been estimated that the annual mean total nitrogen dry deposition in the Dominguez Channel watershed is 44 g N/ha/day. (Lu, Schiff, Stozenbach, 2003). In the Los Angeles area, dry deposition appears to contribute more pollutants than wet deposition due to the relatively few rain events in the area. Thus, most studies of atmospheric deposition focus on dry deposition (Lu *et al*. 2003). There are two major pathways for pollutants from atmospheric deposition to enter waterbodies. One is direct deposition (pollutants deposited directly on the water surface) the other is indirect deposition, in which pollutants are deposited in the surrounding watershed and washed into the waterbody during a storm event (Lu, Schiff, Stozenbach, 2003). The amount of nitrogen directly deposited onto Machado Lake is generally small, because the surface area of the lake is small. Based on the surface area of Machado Lake (13.7 ha) and the annual mean nitrogen dry deposition in the Dominguez Channel watershed (44 g N/ha/day) the estimated annual dry deposition of nitrogen to Machado Lake is 220 kg/year. It is assumed that atmospheric deposition is constant and no adjustments are made for precipitation. The amount of nitrogen available for indirect deposition in Machado Lake is unknown, because the fraction of nitrogen that is consumed by terrestrial biota is unknown (Lu, Schiff, Stozenbach, 2003). However, the loading of nitrogen from indirect atmospheric deposition is accounted for in the estimates of stormwater loading from the watershed.



#### 4.2.6 NONPOINT SOURCE RUNOFF

The west side of Machado Lake is bordered by a landscaped park area, which is heavily recreated as part of the Ken Malloy Harbor Regional Park. The lake receives nonpoint source runoff from this area due to rain events and irrigation practices. The primary sources of nutrients would potentially be from fertilizers possibly used on the landscaped areas and bird feces. Staff from the City of Los Angeles Department of Recreation and Parks has reported that they fertilize the landscaped areas once a year in the spring and irrigate the area once per day. The Park Maintenance Supervisor oversees practices at the park and implementation of best management practices in accordance with the department's Integrated Pest Management Program (IPM).

There is a resident and migrant duck and geese population at the lake, which is regularly observed on the west side of the lake. The bird population deposits feces very near the shoreline in various areas; water flowing over these areas could transport nutrients and other pollutants into the lake. This source of nutrient loading to the lake is not quantified because the amount of runoff and nutrient concentrations are unknown. However, this source of nutrients would be included in total nutrient concentration data collected from the lake.

In addition, the golf course on the east side of the lake is a potential nonpoint source of nutrients to Machado Lake. Golf courses are highly managed areas of the urban landscape with typically high nitrogen and phosphorus fertilizer application rates. Studies of nutrient loading from golf courses report fertilizer application rates for the fairways ranging from 49 – 87 kg/ha for nitrogen and 16 – 24 kg/ha for phosphorus (Moss et. al. 2005; King et al. 2007). The greens and tees of the course generally have even higher fertilizer application rates, but these are much smaller areas of the overall golf course. A study to reduce runoff from golf courses showed that peak concentrations in the runoff water generally occur 20 – 40 minutes into the rain or irrigation event and the nutrient concentrations range from approximately 2.0 – 4.0 mg/L and 6.0 -8.0 mg/L for nitrogen and phosphorus, respectively (Bell and Moss, 2005). The potential nutrient loading from the golf course at Ken Malloy Harbor Regional Park is not quantified, because there is no information on the amount of runoff or nutrient concentrations being discharged from the golf course area.



### 4.3 SUMMARY OF ALL SOURCES

The table below provides a summary of the quantifiable nutrient loads entering Machado Lake on an annual basis. Nutrient flux from the sediments and atmospheric nitrogen deposition are the two directly quantifiable nonpoint sources included as part of the total nutrient load. The total annual nitrogen and phosphorus loads are estimated to be 24,327 Kg and 10,421 Kg, respectively.

**Table 14 Total annual nutrient load entering Machado Lake**

| Source | Total N (Kg) | Total P (Kg) | Ortho – P (Kg) | Inorg –N (Kg) |
|---|---|---|---|---|
| External Load (table 10) | 7,587 | 3,260 | 737 | 3,736 |
| Sediment Flux | 16,520 | 7,161 | 4,963 | 16,520 |
| Atmospheric Dep. | 220 | | | |
| **Total Annual Load** | **24,327** | **10,421** | **5,700** | **20,256** |

## 5 LINKAGE ANALYSIS

The linkage analysis established the relationship between the nutrient loading to Machado Lake and the numeric targets established to measure attainment of beneficial uses. It is also used to establish a basis for allocating nutrient loads to external and internal sources.

### 5.1 NUTRIENT NUMERIC ENDPOINTS MODEL

The Nutrient Numeric Endpoints Model (NNE) was used to establish the linkage between nutrient loading to Machado Lake and the predicted water quality response. As described in the numeric targets section, the NNE BATHTUB spreadsheet tool was developed by Tetra Tech with support by US EPA Region IX and the State Water Resources Control Board. The NNE BATHTUB spreadsheet tool is a user friendly arrangement of the Army Corps of Engineers BATHTUB model (Walker, 1987, 1996) used to analyze the response of lake water quality to different nutrient loading situations. Tetra Tech configured the BATHTUB model to be used in an excel spreadsheet format. The model performs water and nutrient balance calculations under steady-state conditions. Eutrophication related water quality conditions are expressed in terms of total phosphorus, ortho-phosphorus, total nitrogen, inorganic nitrogen, chlorophyll *a*, transparency (Secchi depth), and hypolimnetic oxygen deletion rates. These conditions are predicted using semi-empirical relationships developed and tested on a wide range of reservoirs.



The conceptual model for Machado Lake (Figure 5) provides the rationale for applying the NNE BATHTUB spreadsheet tool to Machado Lake for TMDL development. Machado Lake is modeled as an ecosystem subject to nutrient mass balances. The NNE considers chemical, physical, and biological aspects of the system. The input side of the mass balance requires information such as water inflow and nutrient loading; while the output includes factors such as residence time, overflow, and evaporation.

The following assumptions underlie the linkage analysis. Inputs from storm drains and overland flow occur during wet weather and are negligible during dry weather. Also, during many wet weather events the input volume exceeds the lake volume. Under dry weather conditions, the output mechanisms include evaporation and sedimentation.

Because the water and pollutant transport mechanisms are different during wet and dry weather, and because the input volume exceeds the lake volume during wet-weather events, in-lake concentrations of total nitrogen and phosphorus are assumed to be equivalent to the concentrations discharging from the storm drain during and after the storm event. With the seasonal return of dry weather, evaporation and in lake processes such as sedimentation, resuspension, and nutrient flux alter the concentrations of nitrogen and phosphorus in the lake. Absent flow into the lake for flushing, nutrient concentrations increase with time.

The NNE BATHTUB spreadsheet tool allows the user to input physical, chemical, and biological parameters. The input parameters are listed below.

- Lake volume
- Lake surface area
- Average depth

- Mixed depth
- Net evaporation – precipitation rate
- Secchi depth at typical chlorophyll *a*
- Typical chlorophyll *a*
- Total phosphorus load
- Ortho – phosphorus load
- Total nitrogen load
- Inorganic nitrogen load
- Inflow volume

The model allows the user to analyze many different nutrient loading scenarios and evaluate the lake response. Likewise, the user may specify a chlorophyll *a* concentration or change in Secchi depth and the model will predict the probability of exceeding the target under the specified nutrient loading. Additionally, the model will show allowable nitrogen and phosphorus loading combinations to meet the target.

#### 5.1.1 Calibration and Application

The empirical equations implemented in the NNE BATHTUB Tools spreadsheet model are generalizations about reservoir behavior. When applied to a particular lake, measured observations may differ from model predictions. These differences represent data limitations and unique features of the specific lake. These differences can be represented in the model by a calibration factor. The model should be calibrated to match the predicted results with observed data in the site specific lake by modifying the calibration factor before the model is used to predict water quality. The calibrated model can then be used to predict changes in the lake water quality based on various reduced loading scenarios, assuming that the calibration factors remain constant.

To calibrate the model, the input parameter information of Machado Lake is employed. The calibration factor for total phosphorus can be adjusted to match the model results with the measured data collected in 2006 and 2007. The predicted results for three calibration factors used in the model against measured data of total phosphorus and total nitrogen are shown in Figure 12. It can be seen that the results for calibration factor of 0.2 is the best fit with measured data and hence the calibration factor for total phosphorus of 0.2 is selected for Machado Lake. The chlorophyll *a* calibration factor can also be adjusted to match the model results with measured data. The predicted results of four calibration factors applied in the model against measured data of total phosphorus and chlorophyll *a* are shown in Figure 13. The results for the calibration factor 1.2 are the best fit with the measured data; therefore, 1.2 is used as the chlorophyll *a* calibration factor.



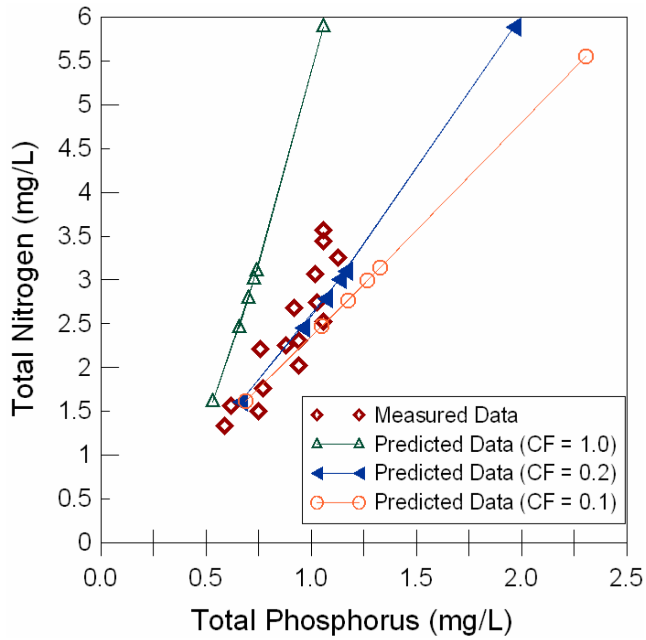


**Figure 12 NNE calibration - Relationship between total phosphorus and total nitrogen**

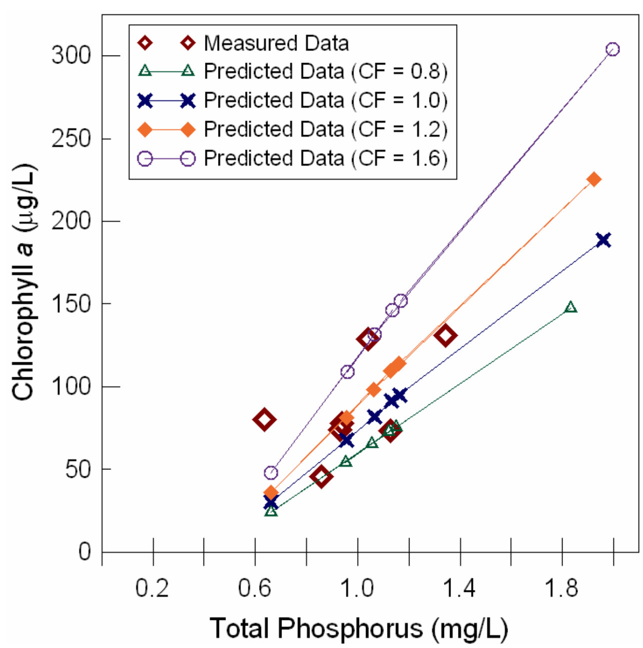


**Figure 13 NNE calibration - Relationship between total phosphorus and chlorophyll *a* concentration in the lake**

This model was selected as part of the development of the Machado Lake Nutrient TMDL because it is a straightforward and effective tool for predicting the growing season water quality of the lake. The Table 15 shows both the measured and predicted growing season water quality results for Machado Lake. There is very good to good agreement between the NNE predicted and measured results for the average chlorophyll *a*, median Secchi depth, total phosphorus, and total nitrogen concentrations with a Relative Percent Difference (RPD) of 2, 0, 7 and 15 percent, respectively. The widest discrepancy found between measured and predicted data was for total nitrogen; the NNE under predicted TN concentration by about 15 percent. In general the model was successful in predicting the water quality of Machado Lake.

**Table 15 NNE predicted and measured growing season water quality**

| Growing Season - Summary Results based on annual nutrient loading | | | |
|---|---|---|---|
| | NNE Result | Measured Data | Relative Percent Difference |
| Avg. Chl a (ug/L) | 89.8 | 91.8 | 2 |
| Median Secchi Depth (cm) | 0.3 | 0.3 | 0.0 |
| TP (mg/L) | 1 | 1.07 | 7 |
| TN (mg/L) | 2.6 | 3.07 | 15 |

### 5.1.2 Sensitivity Analysis

Additionally, a sensitivity analysis for the various model input parameters was completed. The following parameters were included in the sensitivity analysis, for the entire results of the sensitivity analysis please see the Technical Memo for the Machado Lake Eutrophic, Algae, Ammonia, and Odors (Nutrient) TMDL.

- Lake volume
- Inflow
- Total phosphorus load
- Total nitrogen load
- Calibration factor – P concentration
- Calibration factor – N concentration
- Calibration factor – Chlorophyll *a* concentration

The sensitivity analysis demonstrated that lake volume will strongly affect the total P concentration in the lake; an eighty percent decrease in lake volume will result in a 73 percent increase in total phosphorus concentration. However, for total nitrogen an eighty percent decrease in volume is expected to only result in an 18 percent increase in concentration. It appears that changes in the lake volume had very little affect on Secchi depth or chlorophyll *a* concentration in the lake. Likewise, the total phosphorus, nitrogen, and chlorophyll *a* concentrations decrease with an increase in lake inflow. The Secchi depth increases (i.e. greater water transparency) with increased lake inflow.

Expectedly, as the total phosphorus load to the lake increases the total phosphorus concentration in the lake increases and the nitrogen concentration is unchanged. The sensitivity analysis predicts a dramatic initial increase in chlorophyll *a* concentration with the initial increase in phosphorus loading however; it quickly becomes constant and remains relatively stable even with additional phosphorus loading (Figure 14).

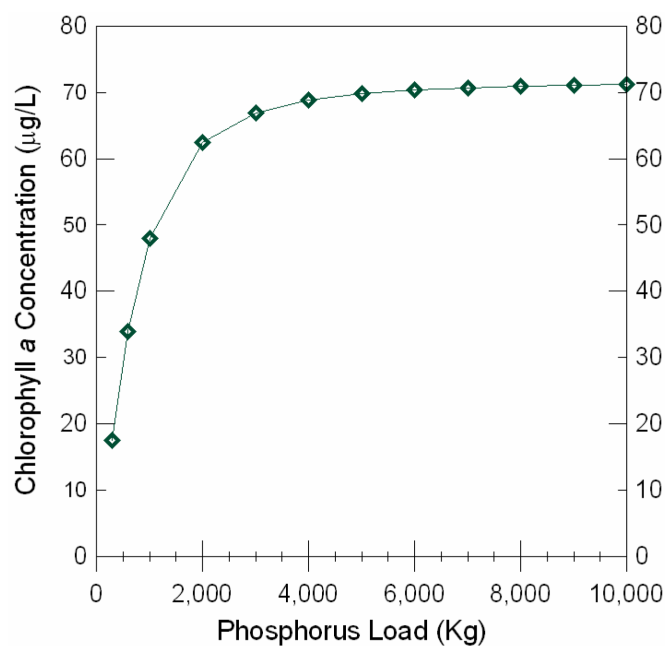


**Figure 14 NNE Sensitivity analysis - Chlorophyll *a* response to phosphorus load**

Similarly, the concentration of total nitrogen in the lake increases with increased nitrogen loading and the total phosphorus concentration is unchanged. Figure 15 below shows the chlorophyll *a* concentration steadily increasing with increasing nitrogen loading up to 15,000 Kg; however it does appear that eventually the chlorophyll *a* concentration would level off and remain unchanged even with additional nitrogen loading. Considering both phosphorus and nitrogen loading and chlorophyll response in the lake; it appears the lake is nitrogen limited.



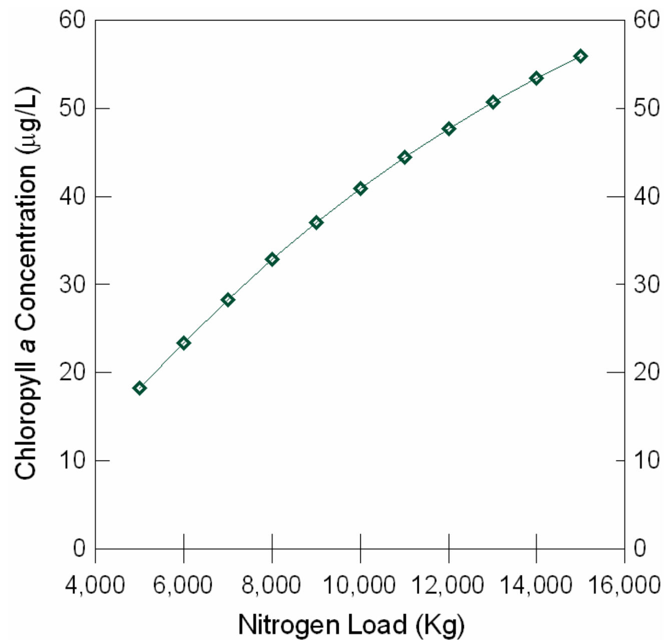


**Figure 15 NNE Sensitivity analysis - chlorophyll *a* response to nitrogen load**

A sensitivity analysis was also done on the NNE calibration factors. This analysis determines what are the most sensitive calibration factors and for which factors calibration is most important. The sensitivity analysis of the phosphorus calibration factor ($K_p$) demonstrates the importance of calibrating the model with respect to phosphorus (Figure 16). As previously, described the model was calibrated with respect to total phosphorus ($K_p$). The calibration factor is 0.2 and was applied in all of the NNE analysis for the development of this TMDL.

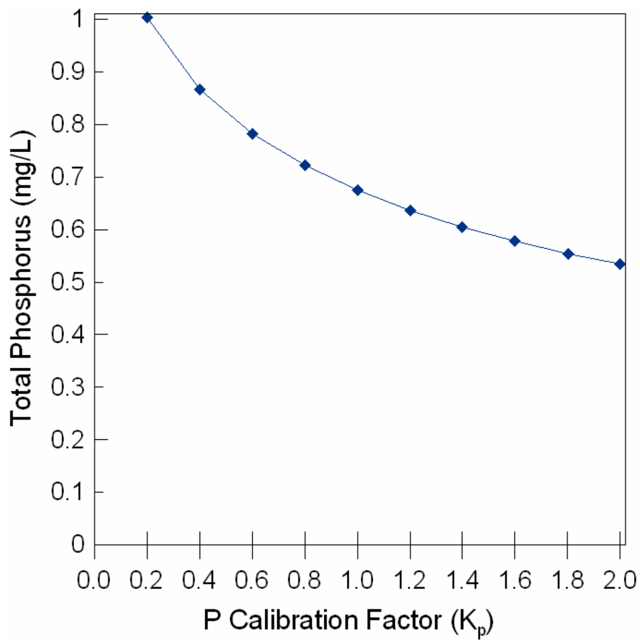


**Figure 16 NNE Sensitivity analysis - total phosphorus relationship with the P calibration factor (Kp)**

In comparison, the sensitivity analysis of the total nitrogen calibration factor ($K_n$) revealed that it is less sensitive than total phosphorus and it could be expected that the model would perform reasonably well with default calibration factor of one (Figure 17). In fact, there is less than 10 % relative percent difference for the total nitrogen results predicted by both the minimum calibration factor (0.2) and maximum calibration factor (2), when compared to the results predicted by the default calibration factor of one.

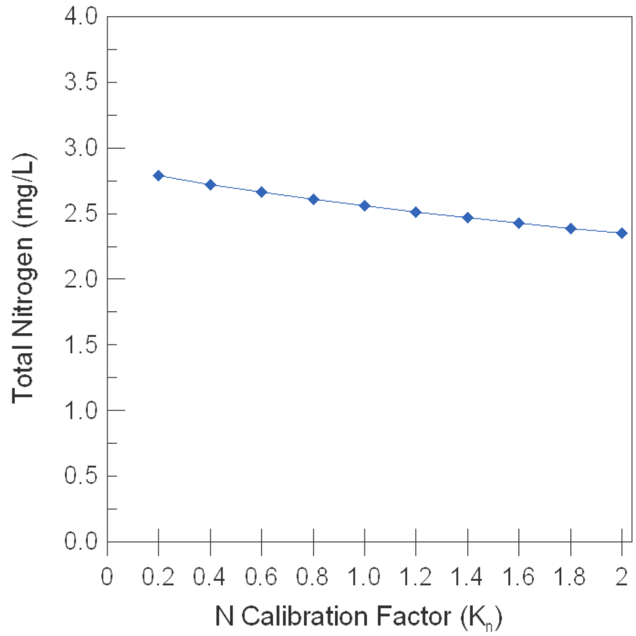


**Figure 17 NNE Sensitivity analysis - total nitrogen relationship with the N calibration factor (Kn)**

The sensitivity analysis of the chlorophyll *a* calibration factor ($K_c$) demonstrated that it is an extremely sensitive parameter of the NNE model (Figure 18). The relative percent difference of the results predicted by the default calibration factor (1) and the minimum calibration factor in this analysis (0.2) was 133 percent. Likewise, the RPD between the default predicted results and the maximum calibration factor predicted result was 67 percent. As previously, described the model was calibrated with respect to chlorophyll *a* ($K_c$). The calibration factor is 1.2 and was applied in all of the NNE analysis for the development of this TMDL.

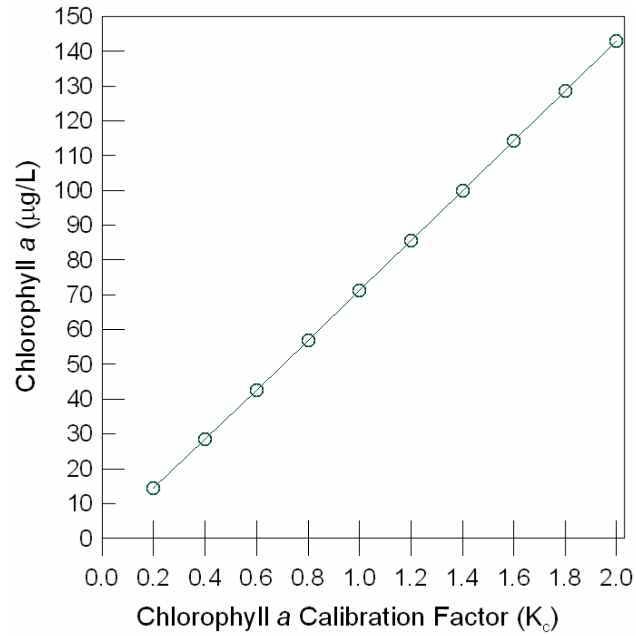


**Figure 18 NNE Sensitivity analysis - Chlorophyll *a* relationship with chlorophyll calibration factor ($K_c$)**



### 5.1.3 Summary of Model

Overall the Nutrient Numeric Endpoints model provides an understanding of the relationship between nutrient loading and the TDML targets. The model is able to predict the lake water quality within acceptable limits and is shown to be an effective tool. Moreover, based on evaluating the water quality response to nutrient loading scenarios in the NNE model and the review of the characteristics of eutrophication and relationships between phosphorus, nitrogen, and algal biomass it is expected that assigning waste load and load allocations for total nitrogen (which includes ammonia) and phosphorus will address the 303(d) listing of eutrophic, algae, ammonia, and odors. The control of nutrient loading to lake, from both external and internal sources, will address the cause of eutrophication (increased nutrient loading) and is critical to treating the symptoms of eutrophication, such as excessive algal biomass and low dissolved oxygen concentrations. Likewise, a reduction in total nutrients will serve to address foul odor impairment, because odor problems can often be caused by the decay process of large algal blooms or as a result of fish kills due to low dissolved oxygen levels caused by excessive respiration and decay of algae.

# 6 Waste Load and Load and Allocations

This section explains the development of the loading capacity and allocations for nutrients in Machado Lake subwatershed. EPA regulations require that a TMDL include waste load allocations (WLAs), which identify the portion of the loading capacity allocated to existing and future point sources (40 CFR 130:2(h)) and load allocations (LAs), which identify the portion of the loading capacity allocated to nonpoint sources (40 CFR 130.2 (g)).



## 6.1 PHOSPHORUS LOAD CAPACITY FOR MACHADO LAKE

The phosphorus loading capacity is based on the relationship between phosphorus loading from both internal and external sources and the predicted in lake phosphorus concentrations generated by the NNE model. The loading capacity was developed to ensure attainment of the total phosphorus numeric target. The figure below demonstrates the relationship between phosphorus loading and the in lake growing season total phosphorus concentration (Figure 19). Based on the results of the NNE model, the total phosphorus loading capacity is 825 Kg per year to meet the total phosphorus numeric target of 0.1 mg/L. This loading capacity was developed under critical conditions when the lake volume was considerably reduced due to drought conditions.

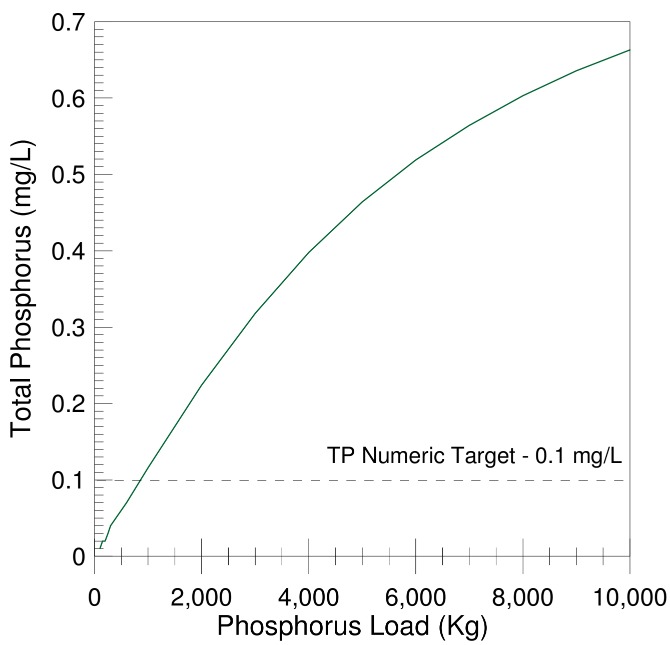


**Figure 19 Relationship between phosphorus load and in lake phosphorus concentration**

## 6.2 Nitrogen Load Capacity for Machado Lake

The nitrogen loading capacity is based on the relationship between nitrogen loading from both internal and external sources and the predicted in lake nitrogen concentration generated by the NNE model. The loading capacity was developed to ensure attainment of the total nitrogen numeric target. The figure below demonstrates the relationship between nitrogen loading and the in lake growing season total nitrogen concentration (Figure 20). Based on the results of the NNE model, the total nitrogen loading capacity is 8,800 Kg per year to meet the total nitrogen numeric target of 1.0 mg/L. This loading capacity was developed under critical conditions when the lake volume was considerably reduced due to drought conditions



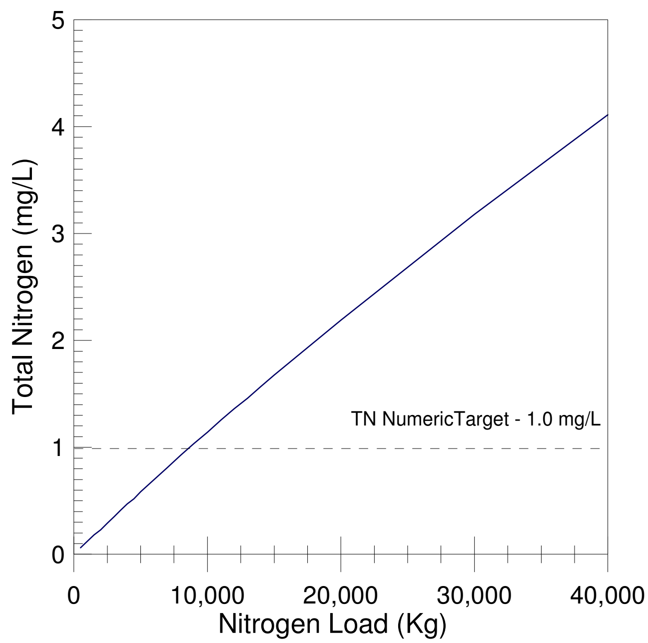


**Figure 20 Relationship between nitrogen load and in lake nitrogen concentration**

## 6.3 Comparison of Current Loads and Loading Capacity for Phosphorus and Nitrogen

Table 16 presents the percent reduction required to meet the total nitrogen and total phosphorus loading capacity. A portion of the total annual load is considered to be removed from the lake to due to outflow to the harbor (Technical Memo, Lai 2007). The remaining nutrient load to the lake is used to calculate the percent reduction required. A

47 percent reduction is needed in total nitrogen loading and a 91 percent reduction in total phosphorus loading to the lake.

**Table 16 Machado Lake current annual nutrient loading and loading capacity**

| | Total Annual Load (Kg) | Load Discharged in Outflow (Kg) | Remaining Load to Lake (Kg) | Loading Capacity (Kg) | Percent Reduction Required |
|---|---|---|---|---|---|
| Total Nitrogen | 24,327 | 7,587 | 16,740 | 8,800 | 47 |
| Total Phosphorus | 10,421 | 845 | 9,576 | 825 | 91 |

## 6.4 ALLOCATIONS

This section summarizes the allocations for urban stormwater dischargers (MS4, Caltrans, general construction and general industrial) and nonpoint sources, primarily internal loading from the lake. The final waste load and load allocations are assigned as concentration based allocations of 0.1 mg/L and 1.0 mg/L as monthly averages for total phosphorus and total nitrogen, respectively. The allocations are assigned as concentrations because typically a single large storm event generates a greater volume of water than the lake volume thus, the in lake concentrations are equivalent to the concentrations after the storm event. Also, in lake storage and recycling mechanisms such as luxury uptake by plants and sediment dynamics can allow nutrients to be used as needed regardless of the rate of delivery to the lake.

Tables 17 and 18 present the interim and final annual waste load and load allocations for the various dischargers. The interim allocations allow time for the discharges to implement measures necessary to achieve the final allocations. The interim WLAs and LAs are based on current in lake concentrations and require a reduction in concentration over time. The initial interim total nitrogen and phosphorus waste load and load allocations are set as 95$^{th}$ percentile of current concentrations in the lake. The 95$^{th}$ percentile of current total nitrogen and total phosphorus concentrations in the lake are 3.36 mg/L and 1.18 mg/L, respectively. The allocations presented in the tables are based on the loading capacities presented in Table 16.

**Table 17 Interim and final Waste Load Allocations for total phosphorus and total nitrogen**

| Waste Load Allocations | Years After Effective Date | Interim Total Phosphorus WLAs (mg/L) | Interim Total Nitrogen (TKN + NO3-N + NO2-N) WLAs (mg/L) |
|---|---|---|---|
| MS4 Permittees[1], Caltrans, General Construction and Industrial Stormwater permits | 1 | 1.18 | 3.36 |
| | 5 | 1.18 | 1.68 |
| | 8.5 (Final WLAs) | 0.10 | 1.00 |

**Table 18 Interim and final Load Allocations for total phosphorus and total nitrogen**

| Load Allocations | Years After Effective Date | Interim Total Phosphorus LAs (mg/L) | Interim Total Nitrogen (TKN + NO3-N + NO2-N) LAs (mg/L) |
|---|---|---|---|
| Internal Nutrient Load (City of Los Angeles Dept. of Recreation and Parks) | 1 | 1.18 | 3.36 |
| | 5 | 1.18 | 1.68 |
| | 8.5 (Final LAs) | 0.10 | 1.00 |

Table 19 presents the current total nitrogen and phosphors concentrations estimated in stormwater discharges and measured lake wide concentrations, with the estimated percent reductions needed to attain the concentration based TMDL allocations.

**Table 19 Current nutrient concentrations and percent reduction to attain allocations**

| Constituent | Estimated Average Stormwater Conc. (mg/L) | Waste Load Allocation (mg/L) | Percent Reduction |
|---|---|---|---|
| Total Phosphorus | 0.37 | 0.1 | 73 |
| Total Nitrogen | 0.86 | 1 | 0 |
| | | | |
| **Constituent** | **Average Lake Conc. (mg/L)** | **Load Allocation (mg/L)** | **Percent Reduction** |
| Total Phosphorus | 0.98 | 0.1 | 90 |
| Total Nitrogen | 2.69 | 1 | 63 |

[1] Municipal Separate Storm Sewer System (MS4) Permittees including: Los Angeles County, Los Angeles County Flood Control District, and the Cities of Carson, Lomita, Los Angeles, Palos Verdes Estates, Rancho Palos Verdes, Redondo Beach, Rolling Hills, Rolling Hills Estates, and Torrance.

# 7 MARGIN OF SAFETY

TMDLs must include an explicit and/or implicit margin of safety (MOS) to account for uncertainty in determining the relationship between pollutant loads and impacts on water quality. An explicit MOS can be provided by reserving (i.e. not allocating) part of the TMDL; thus requiring greater source load reductions. An implicit MOS can be provided by conservative assumptions in the TMDL analysis.

There are some uncertainties in the Machado Lake Nutrient TMDL. Sources of this uncertainty include limited data from the stormdrains entering the lake and the inherent seasonal and annual variability in delivery of phosphorus and nitrogen for external sources and nutrient cycling within the lake. Due to the uncertainty, staff selected conservative numeric targets by establishing the targets under a critical lake volume when nutrient concentrations would be increased. Likewise, conservative assumptions were made when developing the loading and allocations, by assuming a constant value for internal loading. Moreover, the load capacity was based on dry weather critical conditions when the lake level is reduced and therefore loading capacity is reduced. These conservative approaches address the MOS implicitly.



# 8 CRITICAL CONDITIONS

TMDLs must include a consideration of critical conditions and seasonal factors. Due to the wet and dry weather seasons in southern California, the external nutrient loading to Machado Lake generally occurs during winter and spring months in conjunction with storm events. The return frequency of dry weather conditions is approximately 8-9 months. During the dry season the lake receives little external loading. The internal loading of nutrients from sediments provides a source of nutrients to the lake year round. As spring and summer arrive and temperatures increase, both macrophytes and algae increase biomass production through the growing season and take advantage of nutrients available in the lake. As temperatures decline in the fall and winter months, macrophytes and plant biomass will die back and decay releasing nutrients back into the water.

Considering the critical conditions when developing the TMDL provides assurance that even under critical water quality conditions, water quality objectives will be met as the

TMDL is implemented. The critical condition for the attainment of beneficial uses at Machado Lake occurs during the summer months. In the summer there is the release of nutrients from the sediments. At the same time, there is very little water inflow and decreased lake level due to evaporation. These seasonal variations cause increased nutrient concentrations. Moreover, the reduced lake volume during the summer months provides less assimilative capacity. During the dry periods, when there is no external loading to the lake, the internal recycling of nutrients is the most important source of nutrient loading and the driver of eutrophic conditions such as algal blooms. Also, the critical conditions for dissolved oxygen impairments related to algae growth are during the warm dry summer months when algal respiration is highest.

The Machado Lake nutrient TMDL accounts for seasonal and critical conditions of the summer months by assigning a load allocation to the lake sediments and requiring a reduction in this source of nutrients to the lake. This will help to alleviate the source of nutrients during the critical summer months. Likewise, the total nitrogen and phosphorus targets are established as monthly average concentrations to ensure that the lake is regularly meeting water quality objectives and accounting for the delayed response of algal biomass growth in the summer as a result of winter external nutrient loading and changes in seasonal conditions.



# 9 IMPLEMENTATION

This section describes the implementation procedures that could be used to provide reasonable assurances that water quality standards will be met. Compliance with the TMDL is based on achieving the Waste Load and Load Allocations and demonstrating attainment of the Numeric Targets, which are defined as 1.0 mg/L, 0.1 mg/L, 5 mg/L, and 20 ug/L for total nitrogen, total phosphorus, dissolved oxygen, and chlorophyll *a*, respectively. Compliance will require the implementation of programs and lake management activities to reduce nutrient concentrations in the lake, prevent excessive algal biomass growth, maintain an adequate dissolved oxygen concentration, and reduce external nutrient loading. Dischargers may implement structural or nonstructural BMPs and collectively conduct lake management as required to attain the numeric targets and allocations in Machado Lake.

The TMDL Implementation Plan provides a schedule for responsible jurisdictions to implement BMPs and a lake management plan to comply with the TMDL. Key provisions on the implementation plan include:

- Implement stormwater BMPs and lake management activities to reduce nutrient loading and recycling within the lake
- Conduct monitoring to evaluate the progress of implementation measures and compliance with the TMDL
- Reevaluate the WLAs and LAs as necessary



## 9.1 Waste Load Allocation Implementation

### 9.1.1 Stormwater Permits

The following WLAs shall be incorporated into the MS4, Caltrans, and general construction and industrial stormwater NPDES permits: 0.1 mg/L total phosphorus and 1.0 mg/L total nitrogen. The WLAs can be achieved through the implementation of BMPs and lake management projects as outlined in this section.

The control of nutrient loading to Machado Lake results from a reduction in direct nutrient loading from point sources and organic material discharged to the lake. Permitted stormwater dischargers can implement treatment options and BMPs to reduce the nutrient concentration and organic material in the discharge. It is likely that a series of BMPs will need to be implemented to meet the allocation. To address nutrient loading to Machado Lake, a number of possible actions were identified and their effectiveness addressed.

- **Diversion and Treatment**

Diversion and treatment programs would include the installation of facilities to divert stormwater or provide capture and storage of dry and or wet weather runoff with diversion of the stored runoff to location for treatment. Once the water was treated a portion or all of it would be routed back to the lake. Treatment options to reduce nutrients could include sand or media filters or alum injection systems. A typical sand/organic filter system contains two or more chambers. The first is the sedimentation chamber for removing floatables and heavy sediments. The second is the filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. The results of pollutant removal effectiveness vary, but typical total phosphorus removal effectiveness is approximately 60 - 80.percent (CASQA, 2003). Treatment effectiveness is somewhat less for total nitrogen and ranges from 30 – 50 percent removal (EPA, 2007).

D R A F T

- **ALUM INJECTION SYSTEMS**

Alum injection systems are another treatment option for dry weather or stormwater runoff. Alum injection is the process of adding aluminum sulfate salt (alum), to stormwater prior to discharge into the lake. The systems can be installed and sited at appropriate locations in the watershed. Alum injection systems (AISs) have been used successfully in treating urban stormwater runoff that was significantly impairing several lakes in Florida. Alum fixes itself to common pollutants, such as phosphorus, and the floc settles from the water column. Studies of the effectiveness of nutrient removal report demonstrate 30 - 90 percent removal for nitrogen and phosphorus. Also traditional stormwater BMPs such as vegetated swales and filter strips can be used to effectively reduce nutrient loading. The range of removal efficiency is 20 – 80 percent (CASQA, 2003). The implementation schedule allows sufficient time for implementation of the BMPs.

The following are some examples of lake management implementation actions that could be undertaken by responsible parties for the lake.

- **DREDGING/HYDRAULIC DREDGING**

Dredging is the removal of accumulated sediments from the lake bottom. In general surface layers of loose nutrient rich organic material are removed. Dredging should be considered in situations where studies have demonstrated that the lake sediments are a considerable source of nutrient loading to the lake. A method of sediment removal from lakes is hydraulic dredging. A hydraulic dredge floats on the water and is approximately the size of a boat. It has a flexible pipe that siphons a mix of water and sediment from the bottom of the lake. The flexible pipe is attached to a stationary pipe that extends to an offsite location. The sediment that is removed from the lake bottom is pumped to a settling pond to dry. Hydraulic dredging does not require draining the lake or damage to the shoreline of the lake; however it can cause damage to aquatic life, create short term turbid conditions, and low dissolved oxygen levels. Hydraulic dredging does require careful planning and mitigation for non target disturbance.

- **AERATION SYSTEM**

The water quality in Machado Lake could be improved by installing aeration systems at various locations, which would help prevent an anoxic environment that can especially stressful for fish and even lead to fish kills. In general, aeration systems work by destratifying the lake through artificial circulation that mixes the water column and prevents the lake from becoming stratified (due to temperature), particularly during the summer months.



- **INCREASE AND/OR MAINTAIN LAKE LEVEL**

Maintaining an optimal lake level is an important aspect in maintaining good lake water quality. In warm climates with short wet seasons a direct source of supplemental water with low nutrient concentrations could be used to help off set evaporative losses from the lake. Field data from Machado Lake has shown that the lake looses approximately 0.5 meters of water due to evaporation during the summer months. A supply of supplemental water would help to maintain the lake level and water quality through the summer months, which is considered the critical condition for the lake

- **FLOATING ISLANDS / HYDROPONIC NESTING ISLANDS**

Floating islands are constructed islands that provide terrestrial and aquatic habitat while at the same time reducing nutrient concentrations in the lake. The island provides nesting and resting habitat for bird species and the roots below the water provide fish habitat. Floating islands are beneficial in removing nutrients from the water column because the roots of these plants are exposed in the water column instead of rooted in the sediments of the lake. Plants on the floating island should be harvested occasionally in order to maintain actively growing vegetation and maximum nutrient uptake.

- **NUTRIENT INACTIVATION – ALUM TREATMENT**

Aluminum sulfate (Alum) is generally used to inactivate nutrients in the sediments or precipitate phosphorus from the water column. Alum is applied to the lake and it will form a floc of aluminum hydroxide precipitate, which will settle and remove phosphorus from the water column through precipitation. Once the floc settles on the lake bottom, it forms a capped layer that will prevent the phosphorus flux from the sediment into the water column. Phosphorus, released from the sediments, combines with the alum and is not released into the water column where it would be biologically available for algal growth. This should lead to a decreased algal biomass in the lake due to the decreased availability of a key nutrient for algal growth. The amount of time the alum treatment is effective depends on the amount of alum applied and the depth of the lake. Alum treatment in shallow lakes for phosphorus inactivation is estimated to last approximately eight years, although it is possible for the treatment to last longer.

### ■ FISHERIES MANAGEMENT

Removal of Carp or other benthic fish would prevent the exacerbation of the nutrient problem. Additionally to balance the fish community the lake could be stocked with a piscivore such as large mouth bass or crappie. The goal of fisheries management is to create balance between the algal, zooplankton, and fish communities; this will help to create a system with low chlorophyll *a* concentrations. To accomplish this, there must be enough zooplankton grazing of the algal community to control algal growth and prevent blue green algae blooms. This is accomplished by controlling the population of zooplanktivorus fish (fish that eat zooplankton, such as – threadfin shad) with piscivore fish (fish that eat fish, such as– large mouth bass). This approach may have limited direct impact reduced nutrient loading; however the impact on improved water quality by have a more balanced food-web system can be substantial.

### ■ MACROPHYTE MANAGEMENT AND HARVESTING

Macrophytes, aquatic plants, play an important role in nutrient cycling in lakes and overall ecosystem stability and diversity. Macrophytes are often the primary source of organic matter in lakes and can colonize water depths up to 3 meters if light availability is sufficient (Wetzel, 2001). Rooted macrophytes contribute to the nutrient cycle in lakes by absorbing nutrients from the sediments and then upon plant senescence the nutrients are released into the water column. This cycle of growth and decay can benefit lake management and nutrient reduction if the plants are harvested at the peak of growth and the harvested material is removed from the lake. In this way the nutrients are permanently removed from the ecosystem instead of being recycled. Likewise, macrophytes provide important habitat for invertebrates and fish and promote a balanced ecosystem. Rooted macrophytes also help to stabilize lake sediments and reduce wind sediment resuspension.

### 9.2 LOAD ALLOCATION IMPLEMENTATION

Load allocations addressing nonpoint sources of nutrients will be assigned to internal sources. Two primary federal statutes establish a framework in California for addressing nonpoint source (NPS) water pollution: Section 319 of the Clean Water Act (CWA) of 1987 and Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). In accordance with these statutes, the state assesses water quality associated with nonpoint source pollution and develops programs to address NPS. In 2004, The State Water Resource Control Board (SWRCB), in its continuing efforts to control NPS pollution in California, adopted the Plan for California's Nonpoint Source Pollution Control Program (NPS Program Plan). The NPS Program Plan prescribes implementation and monitoring of Management Practices to address nonpoint source pollution.

Two options are available to implement the LAs assigned to internal loading sources: (a) Regional Board or the Executive Officer, if delegated authority by the Regional Board, enters into an Memorandum of Agreement (MOA) with Responsible Jurisdictions and (b) the Regional Board Executive Officer issues a Cleanup and Abatement Order or other appropriate regulatory mechanism.

A MOA may be entered into by the Regional Board and responsible parties to implement the load allocations of the Machado Lake Nutrient TMDL. The MOA shall meet requirements pursuant to the development of a non-regulatory implementation program as presented in Water Quality Control Policy for Addressing Impaired Waters: Regulatory Structure and Options (State Board Resolution 2005-0050) section 2 C ii and requirements of this TMDL.

In order for the MOA to be a valid non-regulatory implementation program adopted by the Regional Board it shall include the following stipulations.

- The MOA directs development of a monitoring and reporting program plan that addresses the impaired water as approved by Regional Board's Executive Officer.
- The MOA contains conditions that require trackable progress on attaining load allocations and numeric targets. A timeline shall be included that identifies the

point or points at which Regional Board regulatory intervention and oversight will be triggered if the pace of work lags or fails.

- The MOA contains a provision that it shall be revoked by the Regional Board based upon findings by the Executive Officer that the program has not been adequately implemented, is not achieving its goals, or is no longer adequate to restore water quality.
- The MOA shall be consistent with the Nonpoint Source Pollution Control Program.

Responsible parties entering into a MOA with the Regional Board shall submit and implement a Lake Water Quality Management Plan. The Lake Water Quality Management Plan must be approved by the Executive Officer and may be amended by Executive Officer approval, as necessary. The California Department of Fish and Game will be consulted on elements of the Lake Water Quality Management Plan relating to fisheries management. The Lake Water Quality Management Plan shall include a Monitoring and Reporting Program (MRP) plan to address appropriate water quality monitoring and a clear timeline for the implementation of management practices to reduce nutrient loading to the lake. The Lake Water Quality Management plan shall include annual reporting requirements. The annual report shall include monitoring results demonstrating either improvements in water quality or continued impairment and demonstrating progress on the implementation of lake management projects to improve water quality.

The Lake Water Quality Management Plan shall achieve compliance with the load allocations through the implementation of lake management strategies to reduce and manage internal nutrient sources. The lake management implementation actions may include, but are not limited to the following:

- Lake dredging/hydraulic dredging
- Aeration system
- Hydroponic Islands
- Alum treatment
- Fisheries Management
- Wetland restoration
- Macrophyte Management and Harvesting
- Maintain Lake Level – Supplemental Water

Compliance with the load allocations shall be measured in the lake at two locations, one in the north portion and one in the south portion of the lake. The average of these two sampling locations shall determine compliance with the load allocations. The compliance sampling locations must be identified in the MRP for approval by the Executive Officer. MRP shall include SWAMP protocols for nutrient assessment or SWAMP compatible protocols proposed by dischargers and approved by the Executive Officer. In addition to the Lake Water Quality Management Plan and MRP a Quality Assurance Project Plan (QAPP) shall also be submitted to the Regional Board for approval by the Executive Officer to ensure data quality.



One year from the effective date of the TMDL the responsible parties entering into the MOA shall submit a letter of intent, Lake Water Quality Management Plan, Monitoring and Reporting Program Plan and Quality Assurance Project Plan for approval by the Executive Officer in order to be in compliance with the MOA adopted as part of this TMDL. The implementation of the Lake Water Quality Management plan must result in attainment of the TMDL load allocations. Implementation of the MOA, Lake Water Quality Management Plan and progress toward the attainment of the TMDL load allocations shall be reviewed annually by the Executive Officer as part of the annual monitoring report submitted by responsible parties. If the MOA and Lake Water Quality Management Plan are not implemented such that the TMDL load allocations are achieved, the Regional Board shall revoke the MOA and the TMDL load allocations may be implemented through a Clean Up and Abatement Order or other appropriate regulatory mechanism.

## 9.3 Determining Compliance with Targets, Allocations, and TMDL

The goal of the TMDL is to restore all of the beneficial uses of Machado Lake through attainment of water quality objectives. Compliance with this TMDL will be determined through water quality monitoring and comparison with the TMDL waste load and load allocations. The compliance point for the stormwater WLA is in the receiving water body, Machado Lake. The compliance point for responsible parties receiving a load allocation is in the receiving water body, Machado Lake.

Stormwater permittees may be deemed in compliance with waste load allocations by actively participating in a lake water quality management plan to attain the waste load allocations for Machado Lake. Stormwater permittees and the responsible party for the lake would work together to implement lake management programs to attain the TMDL waste load allocations.



Alternatively, MS4 Permittees may be deemed in compliance with waste load allocations by demonstrating a 47 percent reduction for total nitrogen and 91 percent reduction for total phosphorous on an annual mass basis measured at the stormdrain outfall of the permittee's drainage area. Permittees must demonstrate total nitrogen and total phosphorous load reductions to be achieved in accordance with a special study workplan approved by the Executive Officer. Permittees shall develop and a Monitoring and Reporting Program (MRP) for Executive Officer approval. The MRP shall include a requirement that the responsible jurisdictions report compliance and non-compliance with waste load allocations as part of annual reports submitted to the Regional Board. Compliance may also be demonstrated as concentration based monthly averages measured at the stormdrain outfall of the permittee's drainage area.

If water quality improves and the numeric targets for chlorophyll *a* and dissolved oxygen are achieved and the allocations and/or numeric targets for nitrogen and phosphorus have not been achieved, the TMDL may be reconsidered to adjust the allocations and targets. Moreover, if nitrogen and phosphorus allocations and numeric targets are met and the chlorophyll *a* and dissolved oxygen numeric targets are exceeded, the TMDL may be reconsidered to adjust the allocations and targets.

### 9.3.1 COORDINATED COMPLIANCE

Responsible jurisdictions for this TMDL include both point source and nonpoint source dischargers. Compliance with the TMDL may be based on a coordinated Monitoring and Reporting Program and Lake Water Quality Management Plan for point and nonpoint discharges that outline responsibilities for each responsible jurisdiction. Dischargers interested in coordinated compliance shall submit a Coordinated Monitoring and Reporting Program and Lake Water Quality Management Plan that identifies stormwater BMPs, lake management strategies and appropriate monitoring that will be implemented by the responsible jurisdictions and an implementation schedule.

## 9.4 Reconsideration of WLAs and LAs

A number of provisions in the TMDL could provide information that could result in revisions and improvements of the TMDL. In addition, the results of special studies would be useful to re-examine assumptions made in developing this TMDL. Thus, the Implementation Plan includes the provision for reconsidering the TMDL to consider the results of special studies or implementation activities, if appropriate.



## 9.5 Monitoring Plan

The Machado Lake Nutrient MRP plan will be designed to monitor and implement this TMDL. The monitoring plan is required to measure the progress of pollutant load reductions and improvements in water quality. The monitoring plan has several goals.

- Determine attainment of total phosphorus, total nitrogen, ammonia, dissolved oxygen, and chlorophyll *a* numeric targets.
- Determine compliance with the waste load and load allocations for total phosphorus and total nitrogen.
- To monitor the effect of implementation actions on lake water quality

Monitoring will begin sixty days after the Executive Officer approval of the MRP. Field samples and water samples will be collected bi-weekly on a year-round basis. The time of day for sample collection will be considered when developing the sampling schedule. The lake sampling sites will be located in the open water portion of the lake with one in the northern portion and one in the southern portion of the lake. Water samples will be collected from the stormdrains directly discharging to the lake, as necessary.

*In situ* measurements of water quality will be made at each of the sampling stations using a water quality probe (such as YSI or HydroLab). Parameters measured will include:

- Temperature
- Dissolved oxygen
- pH
- Electrical conductivity

The water quality probes will be calibrated in the immediately prior to departure to the field against known pH, EC, and DO solutions. Secchi depth, a measurement of transparency, will also be measured with a standard Secchi disk or other approved method. Additionally, a staff gauge shall be placed in an appropriate location at the lake to measure changes in lake elevation.



Water samples will generally be collected as a surface integrated sample; however if the lake level increases and the lake stratifies, samples will be collected in the epilimnion and the hypolimnion. Water samples will be analyzed for the following constituents.

- Total nitrogen
- Total phosphorus
- Nitrate ($NO_3$-N)
- Total ammonia ($NH_3$-N)
- Ortho-phosphorus ($PO_4$)
- Total Dissolved Solids
- Total Suspended Solids
- Chlorophyll *a*
- Turbidity

Detection limits shall be less than the numeric targets in this TMDL. A monitoring report will be prepared and submitted to the Regional Board annually within six months after the completion of the final sampling event of the year.

If the alternative mass based WLA compliance option is selected an appropriate separate TMDL compliance monitoring plan must be submitted for Executive Officer approval. Annual monitoring reports demonstrating compliance or non-compliance shall be submitted for Executive Officer approval

## 9.6 SPECIAL STUDIES

Additional monitoring and special studies would be useful to evaluate the uncertainties and assumptions made in the development of this TMDL. The results of special studies may be used to reevaluate waste load allocations and load allocations when the Machado Lake Nutrient TMDL is reconsidered.

### VOLUNTARY STUDIES

1 Core flux study to estimate the nutrient flux from sediments under equilibrium conditions as opposed to maximum flux rate. Results from this study would be beneficial to gauge the success of implementation measures such as aeration.

2. A study to understand factors such as nitrogen and phosphorus sedimentation rates (particulate settling velocities), the overall lake sedimentation rate, and sediment resuspension rate. These factors would be important for a Machado Lake nutrient budget and gauging the potential need for periodic hydraulic dredging.
3. A work plan for permittees to assess compliance with TMDL WLAs on a mass basis for total nitrogen and total phosphorous. The work plan should detail testing methodologies, BMPs, and treatments to be implemented to attain and demonstrate a reduction of total nitrogen and phosphorous loading on a mass basis. A final report including the results shall be submitted to the Regional Board for Executive Officer approval.



### 9.7 IMPLEMENTATION SCHEDULE

The TMDL Implementation Schedule is designed to provide responsible jurisdictions flexibility to implement appropriate BMPs and lake management strategies to address nutrient impairments at Machado Lake. Implementation consists of development of monitoring/management plans and work plans by responsible jurisdictions, implementation of BMPs to address external nutrient loading to the lake, implementation of lake management activities to reduce internal sources of nutrients and water column nutrient concentrations. The Regional Board will reconsider the Waste Load and Load Allocation seven and one half years after the effective date of the TMDL.

**Table 20 Implementation Schedule for Machado Lake Nutrient TMDL**

| Task Number | Task | Responsible Jurisdiction | Date |
|---|---|---|---|
| 1 | First interim waste load (WLA) and load allocations (LA) for total nitrogen and total phosphorus apply. | California Department of Transportation (Caltrans), Municipal Separate Storm Sewer System Permittees[2] (MS4 Permittees), City of Los Angeles – Department of Recreation and Parks | Effective Date of TMDL |
| 2 | Responsible jurisdictions shall enter into a Memorandum of Agreement (MOA) with the Regional Board to implement the load allocations. | City of Los Angeles – Department of Recreation and Parks | 6 months from effective date of TMDL |
| 3 | Regional Board staff shall begin development of a Clean Up and Abatement Order or other regulatory order to implement the load allocations if an MOA is not established with responsible jurisdictions. | Regional Board Staff | 6 months from effective date of TMDL |
| 4 | Clean Up and Abatement Order or other regulatory order adopted by the Regional Board if an MOA is not established with responsible jurisdictions. The Clean Up and Abatement Order or other regulatory order shall reflect the TMDL Implementation Schedule. | Regional Board Staff | 1.5 years from effective date of TMDL |
| 5 | Responsible jurisdictions whose compliance is determined as concentration based WLAs measured at end of pipe shall submit a Monitoring and Reporting Program (MRP) Plan to the Executive Officer for approval. | Caltrans, MS4 Permittees | One year from effective date of TMDL |
| 6 | Responsible jurisdictions shall submit a Lake Water Quality Management Plan, MRP Plan and Quality Assurance Project Plan for approval by the Executive Officer to comply with MOA. | City of Los Angeles – Department of Recreation and Parks | One year from effective date of TMDL |
| 7 | Responsible jurisdictions shall submit a work plan for optional special study #3 (if responsible jurisdictions choose to conduct this special study) for approval by the Executive Officer. | Caltrans, MS4 Permittees | One year from effective date of TMDL |

[2] Municipal Separate Storm Sewer System (MS4) Permittees that are responsible for discharges to Machado Lake include: Los Angeles County, Los Angeles County Flood Control District, and the Cities of Carson, Lomita, Los Angeles, Palos Verdes Estates, Rancho Palos Verdes, Redondo Beach, Rolling Hills, Rolling Hills Estates, and Torrance.

| Task Number | Task | Responsible Jurisdiction | Date |
|---|---|---|---|
| 8 | Responsible jurisdictions shall submit work plans for optional special studies #1 and #2 (if responsible jurisdictions choose to conduct special studies) for approval by the Executive Officer. | Caltrans, MS4 Permittees, City of Los Angeles – Department of Recreation and Parks | 1.5 years from effective date of TMDL |
| 9 | Responsible jurisdictions shall begin monitoring as outlined in the approved MRP plan. | Caltrans, MS4 Permittees, City of Los Angeles – Department of Recreation and Parks | Sixty days from date of MRP Plan approval |
| 10 | Responsible jurisdictions shall begin implementation of Lake Water Quality Management Plan. | City of Los Angeles – Department of Recreation and Parks | Sixty days from date of Lake Water Quality Management Plan approval |
| 11 | Responsible jurisdictions whose compliance is determined as concentration based WLAs measured at end of pipe shall submit an Implementation Plan including BMPs to address discharges from storm drains. | Caltrans, MS4 Permittees | Two years from effective date of TMDL |
| 12 | Responsible jurisdictions whose compliance is determined as concentration based WLAs measured at end of pipe shall begin implementation of BMPs to address discharges from stormdrains | Caltrans, MS4 Permittees | Sixty days from date of Implementation Plan approval |
| 13 | Responsible jurisdictions shall submit annual monitoring reports. The monitoring reports shall include a requirement that the responsible jurisdictions demonstrate compliance with the MOA. If the MOA and Lake Water Quality Management Plan are not implemented or otherwise do not result in attainment of load allocations, the Regional Board shall revoke the MOA and the load allocations shall be implemented through a Clean Up and Abatement Order or other regulatory order. | City of Los Angeles – Department of Recreation and Parks | Annually – from date of Lake Water Quality Management Plan approval |
| 14 | Responsible jurisdictions whose compliance is determined as concentration based WLAs measured at end of pipe shall submit annual monitoring reports. | Caltrans, MS4 Permittees | Annually – from date of MPR Plan approval |
| 15 | Optional Special Study #3 completed and final report submitted for Executive Officer approval. | Caltrans, MS4 Permittees | Within 2.5 years of effective date of TMDL |

| Task Number | Task | Responsible Jurisdiction | Date |
|---|---|---|---|
| 16 | Responsible jurisdictions shall submit a MRP Plan and Implementation Plan for the alternative mass based WLA compliance option (if selected), to the Executive Officer for approval. | Caltrans, MS4 Permittees | Within 2.5 years of effective date of TMDL |
| 17 | Responsible jurisdictions shall begin monitoring and implementing projects/programs as outlined in the approved MRP and Implementation Plan for the alternative mass based WLA compliance option. | Caltrans, MS4 Permittees | Sixty days from date of MRP/ Implementation Plan approval |
| 18 | Responsible jurisdictions whose compliance is determined as mass based WLAs measured at end of pipe shall submit annual monitoring reports. | Caltrans, MS4 Permittees | Annually – from date of MPR/ Implementation Plan approval |
| 19 | Optional Special Studies (#1 and #2) completed and Special Study final reports submitted for Executive Officer approval. | Caltrans, MS4 Permittees, City of Los Angeles – Department of Recreation and Parks | Within 3 years of effective date of TMDL |
| 20 | Second interim total nitrogen WLA and LA apply. | Caltrans, MS4 permittees, City of Los Angeles – Department Recreation and Parks | Within 5 years of effective date of TMDL |
| 21 | Regional Board may reconsider the TMDL to include results of optional special studies completed by the responsible jurisdictions and revise numeric targets, WLAs, LAs, and the implementation schedule as needed. | Regional Board | 7.5 years from effective date of TMDL |
| 22 | Responsible jurisdictions shall achieve Final WLAs and LAs for total nitrogen (including ammonia) and total phosphorus and demonstrate attainment of numeric targets for total nitrogen, ammonia, total phosphorus, dissolved oxygen, and chlorophyll a. Responsible parties shall demonstrate attainment of water quality standards for total nitrogen, ammonia, total phosphorus, dissolved oxygen, and biostimulatory substances in accordance with federal regulations and state policy on water quality control. | Caltrans, MS4 Permittees, City of Los Angeles – Department of Recreation and Parks | Within 8.5[3] years of effective date of TMDL |

[3] Based on determination during TMDL reconsideration, the Regional Board may extend the implementation schedule 3.5 years if advanced stormwater treatment or supplemental water sources are required to implement LAs and WLAs.

## 9.8 Cost Considerations

Porter-Cologne Section 13241(d) requires staff to consider costs associated with the establishment of water quality objectives. This TMDL does not establish water quality objectives, but is merely a plan for achieving existing water quality objectives. Therefore, cost considerations required in Section 13241 are not required for this TMDL.

The purpose of this cost analysis is to provide the Regional Board with information concerning the potential cost of implementing this TMDL, and to addresses concerns about costs that have been raised by responsible parties. An evaluation of the costs of implementing this nutrient TMDL amounts to evaluating the costs of remediating nutrient levels in the lake and preventing nutrient loading to the lake from stormwater discharge. This section provides an overview of the costs associated with the typical nutrient management and nutrient reduction implementation methods.

### 9.8.1 Cost of Implementing Nutrient TMDL

The cost of implementing this TMDL will range widely, depending on methods that the responsible parties select to meet the Waste Load and Load Allocations. Based on the implementation measures discussed previously, approaches can be categorized as Machado Lake management and stormwater treatment prior to discharging into Machado Lake. Lake management strategies may be relatively more effective in reducing nutrient concentrations in the lake, since some methods can remove the long accumulated sediment, which is a large source of nutrients. Attainment of the WLA and LA in Machado Lake by only treating incoming stormwater would require more time, and may be season-dependent. However, stakeholders may determine the compliance approach by considering the possible time needed in conjunction with the expense.

#### 9.8.1.1 Lake Management Implementation Options

**Sediment Removal/Hydraulic Dredging**

The depth of Machado Lake ranges from 1 to 3.5 meters, but current measurements are in the range of 0.5 – 1.0 meter. Staff finds it may be feasible to dredge Machado Lake approximately three feet. Considering Machado Lake's surface area of 40 acres, the dredged volume, including the removed sediment and weeds along the shoreline is estimated to be 250,000 cubic yards ($yd^3$). A unit cost of $20 dollars per cubic yard is assumed, which comprises delivery of equipment, setup, operating equipment, pumping, dewatering process or sludge/sediment management, cleaning, labor associated with the above activities, and transporting waste. The estimated cost for the dredging portion of the project is five million dollars ($5,000,000).

The typical solid content of the dredged and untreated sludge is approximately 5 %, which would produce 12,500 cubic yards of sludge with a density of 1000 mg/L after drying. The sludge cake may be disposed of at a cost of 50 cents per pound, depending on the landfill locations, or it may be used as fertilizer. However, sludge from Machado Lake may require special treatment due to the potential for toxic organic substances residing in the sediments.

The total cost to complete hydraulic dredging at Machado Lake is estimated at $5,010,526. Given a compliance schedule of 8.5 years, and the annual interest rate of 6%, the amortized cost for each year would be $967,306 (Table 21).

**Table 21 Summary of estimated cost for hydraulic dredging**

| | Time Required | Volume (cubic yards) | Unit Cost | Total Cost |
|---|---|---|---|---|
| Hydraulic Dredging (including setup, operation, pumping dredged materials and all associated labor) | 8 months | 250,000 | $20/cubic yard | $5,000,000 |
| Sludge Processing and disposal | 8 months | 12,500 (21,050 lbs) | $0.50/lb | $10,526 |
| Total | | | | $5,010,526 |
| Amortized over 8.5 years (6% interest rate) | | | | $967,306 per year |

(Wastewater Engineering Treatment, disposal and Reuse, 3rd edition, Chap 12, Metcalf & Eddy).

D R A F T

**Aeration System**

The water quality in Machado Lake could be improved by installing aeration systems at various locations, which would help to prevent an anoxic environment. Aeration methods are commonly used for lakes, ponds or reservoirs of different sizes. In general, aeration systems work by destratifying the lake through artificial circulation that mixes the water column and prevents the lake from becoming stratified (due to temperature), particularly during the summer months



Purchase and installation of a continuous laminar flow aeration system at Machado Lake is estimated to be $35,000 dollars (Table 22). To enhance the effectiveness of the aeration system, weeds and existing algae should be removed and disposed of outside of the lake. The cost is assessed based on the surface area of Machado Lake. Additional costs include maintenance, utilities, and labor. It is assumed that the system operates 12 hours per day and will be maintained by a technician for one hour each day at the loaded technician wage of $37.50 per hour.

**Table 22 Summary of estimated cost for an aeration system**

| Items | Unit Cost | Total Cost |
|---|---|---|
| Capital Cost (Equipment and Installation) | | $35,000 |
| Pretreatment Maintenance (Algae and Weed Removal) | $6120 for weeds, $4,200 for algae | $10,320 per year |
| Utility | $2.50 per month/surface acre for 12 hour operation. | $1,200 per year |
| Labor | $37.5 per hour for 360 hours | $13,500 per year |
| Sewage Treatment | $3,600 per year | $3,600 per year |
| Total | | $63,620 the first year, $28,620 annually thereafter |

**Increase and/or Maintain Lake Level**

Maintaining an optimal lake level is an important aspect in maintaining good lake water quality. In warm climates with short wet seasons a direct source of supplemental water with low nutrient concentrations could be used to help off set evaporative losses from the lake. This would help to maintain water quality through the summer months, which is considered the critical condition for the lake

The most significant cost of implementing supplemental water is the construction of pipelines. The construction cost depends on factors such as the demand of reclaimed/recycled water supply, and distance from the water recycling facility to Machado Lake. The capital cost for construction may be amortized over 20 years. Eexpenses of purchasing recycled water and maintaining the pipelines can be assessed on an annual basis.



California has encouraged cities to use recycled water for agriculture, landscaping and replenishing lakes. The rate for recycled water is $166 dollars per acre-foot, compared to $600 dollar per acre-foot for potable water (WateReuse Association, 2004). Assuming a surface area of 40 acres and an average depth of 1.5 meters (5 feet), to completely replenish Machado Lake once every month, the water would cost $239,000 for recycled water or $864,000 for drinking water (Table 23). The cost for recycled water may increase if additional treatment for nutrient removal is required.

**Table 23 Summary of estimated cost for supplemental water to maintain lake level**

| Item | Unit Cost | Total Cost |
|---|---|---|
| Construction | Approximate estimate of $500,000 for project with 8.5 year life time. | $96,527 per year after amortized over 8.5 years with an interest rate of 6%. |
| Water | $166 per acre-foot (recycled) $600 per acre-foot (drinking water) | $239,000 per year (recycled water) $864,000 per year (drinking water) |
| Maintenance | 20% of the capital cost of construction. | $10,000 per year |

**Floating Islands/Hydroponic Nesting Islands**

Utilizing floating islands creates a miniature ecological system that consumes nutrients in the lake. Floating islands have plants with roots extending freely into the water to absorb the necessary nutrients for growth. This differs from traditional islands, where plants obtain nutrients from the soil. Another advantage of floating islands is that they provide habitats for wildlife.

The effectiveness of nutrient removal by floating islands largely depends on the surface area of the islands and the intake capability of the plants. Likewise, there can be considerable seasonal difference in the efficiency of nutrient uptake; however due to California's long growing season this method can be effective particularly during the summer months when compliance may be most challenging.

Most floating islands are prefabricated, and fairly economic for installation. They also require minimal maintenance. Assuming that 1% of the lake surface will be installed with floating islands, and each island is 15 square-feet, approximately 1000 floating islands will be installed. A floating island costs $700, not including plants, for a total cost of $700,000 (Table 24).

**Table 24 Summary of estimated cost for floating islands**

| Items | Unit Cost | Total Cost |
|---|---|---|
| Floating Islands | $700/island | $700,000 |
| Plants | $150/ island | $150,000 |
| Installation | $37.5/ loaded labor hour, 8 hours/ island. | $300,000 |
| Maintenance | 5% of all above cost annually | $57,500/year |
| Amortized over 8.5 years (6 % interest rate) | | $279,513/year |

**Fisheries Management**

Removal of Carp or other benthic fish would prevent the exacerbation of the nutrient problem, but would be less likely to immediately mitigate water quality problems. Time and frequency of carp removal will determine the effectiveness. A preliminary study may be needed to understand the population of carp and its spawning season and location. To ensure the interruption of the food web, monthly removal and confirmation of fish population may be necessary. The fish population survey requires a pontoon boat with fish nets, and two people to capture the calculated amount of fish.

Carp removal can be accomplished by applying fish trapnets. Management of fish trapnets requires at least 2 professionals for at least 10 days to remove carp from a 40 acre lake like Machado Lake. To balance the fish community it would be advisable to the restock the lake with a piscivore species such as large mouth bass or crappie. Stocking a lake with fish requires knowledge of suitable species, characteristics of the environment, and the appropriate number of fish. According to a study for Department of Animal Science by University of California at Davis, approximately 100 largemouth bass may be stocked for each surface acre of the lake. The average body weight of median largemouth bass is 1 pound, with cost of $5.00 for each pound including transportation. The total cost of restocking Machado Lake is estimated at $20,000 dollars (Table 25).

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**Table 25 Summary of estimated cost for fisheries management program**

| Items | Unit Cost | Total Cost |
|---|---|---|
| Capital cost (Boat, trailer and accessories) | $10,000 | $10,000 |
| Removal of Carp/fish | $37.50 per hour for two people for 10 days | $6,000 |
| Fish Survey and follow-up assessments (twice/year) | $20,000 | $20,000/year |
| Restocking | $5.00 per pound for 4,000 pounds | $20,000/year |
| Maintenance | $37.50 per hour for two people for 5 days each month. | $36,000 /year |
| Amortized over 8.5 years (6% interest rate) | | $46,811/year |

**Nutrient inactivation – Alum Treatment**

Alum treatment requires addition of aluminum sulfate. Alum interacts with phosphorus to form a floc, which settles at the bottom of the lake. The floc layer will behave as an isolator to stop the release of nutrients from the sediment into water. Based on case studies, alum treatments are effective for most shallow lakes, particularly in reducing internal nutrient loading from the sediment by over eighty percent. Lakes may need to be retreated approximately every eight years.

The primary cost of the alum treatment is the purchase and application of the chemicals, if dredging is not required. It also depends on the frequency of treatment, forms of alum used (wet or dry), dosage rate, and labor. Inclusively, treating lake by alum ranges from $280 to $700 per acre with an average of $450 per acre. Applying the high end of the cost range it is estimated to cost $30,000 for alum treatment for the 40 acre lake.



### 9.8.1.2 Stormwater Treatment Implementation Options

**Sand/Organic Filters**

A typical sand/organic filter system contains two or more chambers. The first is the sedimentation chamber for removing floatables and heavy sediments. The second is the filtration chamber, which removes additional pollutants by filtering the runoff through a sand bed. Properly designed sand/organic filters are effective methods to remove suspended solids, biochemical oxygen demand (BOD), total phosphorus, and fecal coliform bacteria and nutrients from stormwater. The effectiveness of a sand/organic filter system is greatly influenced by the pollutant loadings, and the characteristics of the drainage areas.

The advantage of using a sand/organic filter system includes the relatively high removal rates of specific contaminants, and the production of environmentally-safe waste for landfills. However, the filtering media (i.e., sand and gravel) needs to be replaced or regenerated every 3 to 5 years.

The construction cost of a sand/organic filter system depends on the drainage areas, expected efficiency and other design parameters. Case studies conducted in 1997 indicate cost ranges from $2,360 dollars/acre for areas greater than 30 acres to $18,500 dollars per acre (EPA, 1999). Assuming a unit price of construction to be $2,000 dollars and given the area of Drain 553, and Wilmington Drain and Project 77/510 is approximately 7,000 impervious acres, the overall construction for the sand/organic filter system would cost $14 million dollars (Table 26). Annual maintenance costs average approximately 5% of the construction cost.

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**Table 26 Summary of estimated cost for stormwater treatment filters**

| Items | Unit Price | Total Cost |
|---|---|---|
| Construction cost | $2,000/acre of drainage area | $14,000,000<br>$2,702,769 annually if amortized with an interest rate of 6% for 8.5 years. |
| Maintenance | 5% of the construction cost, annually | $700,000 annually |
| Amortized cost over 8.5 years (6% interest rate) | | $3,402,769 annually |

**Alum Injection System**

Alum injection is the process of adding aluminum sulfate salt (alum), to stormwater. Alum injection systems (AISs) have been used successfully in treating urban stormwater runoff that was significantly impairing several lakes in Florida. Alum fixes itself to common pollutants, such as phosphorus, and the floc settles from the water column. The AIS requires ongoing operation and precipitates from the alum increase the solids that must be disposed. Alum may be injected into stormwater in either a fixed dose or in variable doses according to the flow rate. Previous studies demonstrated that the removal of total phosphorus can reach 95%, and total nitrogen reached 75% (Harper, Herr, Livingston, 1999).

Parameters to be considered for design of the automated alum injection system include the stormwater drainage area, flow rate of stormwater discharge, locations of the system, and the seasonal precipitation. The construction cost for a watershed of 1,500 acres widely ranges from $75,000 to $400,000 with the average capital cost of $1,542 per acre treated. The overall operation and maintenance cost ranges from $27 to $208 per acre treated per year, with the average of $120 dollars per acre per year. With the impervious watershed surface of Drain 553, Wilmington Drain and Project 77/510 at 7,000 acres, the costs are summarized in Table 27 below.

**Table 27 Summary of estimated cost for alum injection system**

| Items | Unit Cost | Total Cost |
|---|---|---|
| Capital Cost | $1,542 per acre | $10,794,000 |
| Operation and Maintenance Cost | $120 per acre per year | $840,000 annually |
| Amortized cost over 8.5 years (6% interest rate) | | $2,923,835 annually |

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**Vegetated Swales and Filter Strips**

Vegetated swales are constructed drainage ways used to convey stormwater runoff. Vegetation in swales allows for the filtering of pollutants, and infiltration of runoff into groundwater. Densely vegetated swales can be designed to add visual interest to a site or to screen unsightly views. Broad swales on flat slopes with dense vegetation are the most effective at reducing the volume of runoff and pollutant removal. Vegetated swales generally have a trapezoidal or parabolic shape with relatively flat side slopes. Individual vegetated swales generally treat small drainage areas (five acres or less).

Filter strips are densely vegetated, uniformly graded areas that treat sheet flow from adjacent impervious surfaces. They reduce runoff velocities, which allow sediment and other pollutants to settle out. The reduced velocities also result in some infiltration. Filter strips are commonly planted with turf grass, but they may also employ native vegetation trees and shrubs to create visual screening and physical barriers. Filter strips are frequently used as a pretreatment system for stormwater that will be treated with other BMPs such as filters or bioretention systems.

The effectiveness of vegetated swales or filter strips depends on slopes of swales, soil permeability, grass cover density, contact time of stormwater runoff and intensity of storm events. The performance of vegetated swales/filter strips may be up to 99% for phosphorus and nitrogen removal depending on design (CASQA, 2003). Vegetated swales or filter strips, based on case studies, are capable of managing runoff from small drainage areas with approximate sizes of 10 acres. The swale size must be increased to address the large drainage areas of tributaries discharging to Machado Lake.

Alternatively, smaller swales may be constructed at multiple sites. Considering a unit swale that is 10 feet wide and 1,000 feet long, which results in a hydraulic residence time of at least 10 minutes, for each 10 acres of drainage area, the ratio of the swale surface area to each draining acre, is 1,000 square feet per acre (CASQA, 2003). Therefore the, total surface area needed to treat a drainage area of 7,000 is estimated to be 160 acres.

Construction of swales begins with site clearing, grubbing, excavation, leveling and tilling, thereafter followed with seeding and vegetation planting. The cost of developing a swale unit is estimated in the range of $6,000 to $17,000 or from $0.25 to $0.5 per square foot. Routine maintenance activities include keeping up the hydraulic and removal efficiency of the channel, periodic mowing, weed control, watering, reseeding and clearing of debris and blockages for a dense, healthy grass cover. The maintenance cost is assessed at 5% of the construction cost annually (Table 28).



**Table 28 Summary of estimated cost for vegetative swales**

| Items | Unit Cost | Total cost |
|---|---|---|
| Construction | $6,000 per unit swale for each 10-acre drainage area | $4,200,000 |
| Maintenance | 5% of construction cost annually | $210,000 annually |
| Amortized cost over 8.5 years (6% interest rate) | | $1,020,830 annually |

#### 9.8.1.3 Cost Comparison

Water quality improvement at Machado Lake can be achieved through lake management which mitigates the nutrient problem in the lake water and by reducing nutrient loading from stormwater discharge. The following table summarizes the estimated total costs for lake management methods (Table 29). The most expensive lake management practice is hydraulic dredging with the capital cost of 5 million dollars, but it is an efficient and effective way to improve water quality in the lake and reduce nutrient loading from the sediments. Other less expensive methods require more time and monitoring to confirm the effectiveness of treatment.

**Table 29 Cost summary for lake management implementation alternatives**

| Lake Management Implementation Alternatives | Hydraulic Dredging | Aeration | Dilution | Floating Islands | Fisheries Management | Alum Treatment |
|---|---|---|---|---|---|---|
| Capital Cost | $5,000,000 | $35,000 | $500,000 | $1,150,000 | $56,000 | $0 |
| Operation and Maintenance Costs, Annual | $10,526 | $28,620 | $249,000 | $57,500 | $36,000 | $30,000 |
| Total Cost, after 8.5 years | $5,089,471 | $278,270 | $2,616,500 | $1,638,750 | $362,000 | $30,000 |
| Amortized Annual Cost | $982,548 | $53,721 | $505,128 | $316,369 | $69,886 | $30,000 |

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The construction and maintenance costs for stormwater treatment are presented in Table 29.

**Table 30 Cost summary for stormwater treatment implementation alternatives**

| Stormwater Treatment Implementation Alternatives | Sand/Organic Filters | Alum Injection System |
|---|---|---|
| Construction Cost | $14,000,000 | $10,794,000 |
| Operation and Maintenance Costs, annually | $700,000 | $840,000 |
| Amortized annual Cost | $3,402,769 | $2,923,835 annually |

Comparing the cost of various implementation methods in the tables above provides an estimate of the cost required to attain the waste load and load allocations set in this TMDL.

# 10 REFERENCES

D R A F T

Anderson, Douglas C., Sartoris, James J., Thullen, Joan J., Reusch, Paul G. 2003. The Effects of Birds on nutrient Removal in a Constructed Wastewater Treatment Wetland. Wetlands. Vol. 23, No. 2 423-435

Bell, Greg, Moss, Justin. 2005. Managing Golf Course Roughs to Reduce Runoff. USGA Turfgrass and Environmental Research Online. Vol. 4 No.12
1-9.

Bloesch, Jürg. 1995. Mechanisms, Measurement and Importance of Sediment Resuspension in Lakes. Marine and Freshwater Research. Vol. 46 295-304

Breukelaar, André, W., Lammens, Eddy, H.R.R., Klein Breteler, Jan, G.P., Tátrai, Istvan. 1994. Effects of Benthivouruous Bream (*Abramis brama*) and Carp (*Cyprinus carpio*) on Sediment resuspension and Concentrations of Nutrients and Chlorophyll *a*. Freshwater Biology. Vol. 32 113-121.

California Stormwater Quality Association, Stormwater Best Management Practice (BMP) Handbooks, 2003.

Canfield, Daniel Jr. 1983. Prediction of Chlorphyll a Concentrations in Florida Lakes: the Importance of Phosphorus and Nitrogen. Water Resources Bulletin. Vol. 19 No. 2 255-262.

Carper, Glenn L., Bachmann, Roger W. 1984. Wind Resuspension of Sediments in a Prairie Lake. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 41 1763-1767.

Dillon, P. J., Rigler, F. H. 1974. The phosphorus – Chlorophyll Relationship in Lakes. Limnology and Oceanography. Vol. 19 (5) 767-773.

Edmondson, W. T. 1994. Sixty Years of Lake Washington: a Curriculum Vitae. Lake and Reservoir Management. Vol. 10 (2) 75-84.

Edmondson, W. T. 1970. Phosphorus, Nitrogen, and Algae in Lake Washington After Diversion of Sewage. Science. Vol. 169 No. 3946 690-691.

Gilbert, Robert. 1999. Calculated Wave Base in Relation to the Observed Patterns of Sediment Deposition in Northeastern Lake Ontario. Journal of Great Lakes Research. Vol. 25 (4) 883-891.

Harper, H. H., Herr, J. L., Livingston, E.H. Alum Treatment of Stormwater: the First Ten Years. New Applications in Modeling Urban Water Systems. CHI, Guelph, Ontario, Canada 1999.

King, K. W., Balogh, J. C., Hughes, K. L.,Harmel, R. D. 2007. Nutrient Load Generated by Storm Event Runoff from a Golf Course Watershed. Journal of Environmental Quality. Vol. 36 1021-1030.

Lu, Rong, Schiff, Kenneth C., Stolzenbach, Keith D. Nitrogen Deposition on Coastal Watersheds in the Los Angeles Region. 2003-2004. Southern California Coastal Water Research Project Annual Report. pp. 73-81.

Lu, R., Turco, R. P., Stolzenbach, S., Friedlander, S. K., Xiong, C., Schiff, K., Tiefenthaler, L., Wang, Guangyu. 2003. Dry Deposition of Airborne Trace metals on the Los Angeles Basin and Adjacent Coastal Waters. Journal of Geophysical Research. Vol. 108 No. D2 11-1 – 11-24.

Moss, Justin, Bell, Gregory E., Kizer, Michael A., Payton, Mark E., Basta, Nicholas T., Zhang, Hailan, Martin, Dennis L. Controlling Nutrient Runoff from Golf Course Fairways Using Vegetative Filter Strips. Oklahoma State University Department of Horticulture and Landscape Architecture. http://home.okstate.edu/Okstate/dasnr/hort/hortlahome.nsf/toc/bell3. Accessed on September 11, 2007.

Moss, Justin, Bell, Gregory E., Kizer, Michael A., Payton, Mark E., Zhang, Hailan, Martin, Dennis L. 2006. Reducing Nutrient Runoff from Golf Course Fairways Using Grass Buffers of Multiple Heights. Crop Science. Vol. 46 72-80.

Persson, Andres, Svensson, Jonas M. 2006. Effects of Benthivorous Fish on Biogeochemical Processes in Lake Sediments. Freshwater Biology. Vol. 51 1298-1309.

Risgaard-Petersen, Nilis., Rysgaard, Soren., Nielsen, Lars Peter., Revsbech, Niels Peter. 1994. Diurnal Variation of Denitrification and Nitrification in Sediments Colonized by Benthic Microphytes. Limnology and Oceanography. Vol. 39(3). 573-579.

Schindler, D. W. 1974. Eutrophication and Recovery in Experimental Lakes: Implications for Lake Management. Science. Vol. 184 897-899.

Seitzinger, Sybil, P. 1988. Denitrification Freshwater and Coastal Marine Ecosystems: Ecological and Geochemical Significance. Limnology and Oceanography. Vol. 33(4 part 2). 702-724.

U.S. EPA. 2000. Nutrient Criteria Technical Guidance Manual Lakes and Reservoirs. EPA 822-B00-001.

U. S. EPA National Menu of Stormwater Best Management Practices http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm. Accessed on September 19 and 20, 2007.

U.S. EPA 1999. Stormwater Technology Fact Sheet – Sand Filters. EPA 832-F-99-007

Wastewater Engineering Treatment, Disposal and Reuse, 3rd edition, Chap 12, Metcalf & Eddy

WateReuse Association, August 27, 2004. Water Reuse News. www.watereuse.org/news/wrnews_082704.htm. Accessed on September 26, 2007

Wetzel, R. *Limnology*. Academic Press, 2001.